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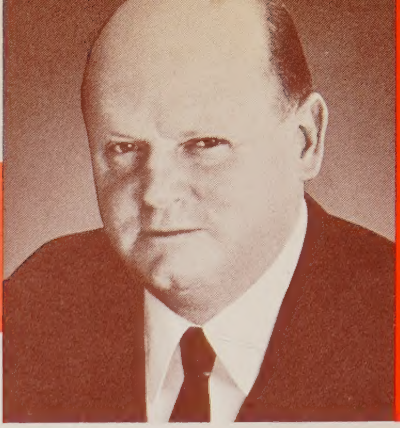
for educators
in the fields of engineering
and allied sciences

Designing for Human Accommodation

The Importance of Engineering in Automobile Styling



YEARS ago, when I started in the automobile business, the automobile designer was a decorator—he merely put the finishing touches on a virtually completed product. Now his interest extends far beyond just surface decoration. Although styling is still the most important part of an automobile designer's work, it is the *final step* of the design process.

The automobile designer now must concern himself with a product from the initial research about its markets, to the last touch of trim and paint. He must accurately analyze and evaluate customer opinion and public preferences. He must understand production facilities and production economics. Designers must apply the science of human engineering to give motorists comfort, convenience, safety and driving ease, as well as eye appeal. And designers nowadays have to be masters at developing the anatomy of the automobile so that the arrangement of mechanical components furnishes the proper architecture or scaffolding upon which he can create a pleasing, exciting image. The artist in him comes into its own as he uses aesthetics to transform lifeless dimensions and statistics into exciting personalities that attract the customer and cause him to buy.

The automobile designer employs diverse personal skills in accomplishing these tasks, but he also relys on trained experts to provide specialized information he may be unable to supply himself. For that reason, we have as members of our design team cost engineers, glass engineers, mechanical engineers, human factors engineers, vehicle aero-dynamics engineers, and stress engineers, to assist our designers in highly technical areas. Furthermore, there is a veritable multitude of other technical specialists, such as plastics engineers, process engineers, layout engineers, architectural engineers, electrical engineers, and methods engineers working as part of the Styling Staff in fabrication and service activities. All are needed today in designing the modern motor car.

In addition, engineering personnel play a prominent part in other capacities here. For instance, six of our ten executive committee members are graduate engineers, including our staff manager who handles administrative matters for us. Six of our chief designers have engineering backgrounds and training that enable them to deal directly with complex engineering problems, while many others have acquired a great degree of engineering know-how and proficiency through practical experience.

As the nature of our work becomes more complicated and we change to keep pace, I expect creative engineering opportunities to increase commensurately, since automobile designers will depend more and more on engineers for cooperative assistance to cope with the complex situations that arise. I am confident that the result will be a higher level of competence in our collective ability as a design staff to create suitable motor cars for future markets.

William L. Mitchell,
Vice President in Charge of Styling Staff

THE COVER

The different sizes, weights, and body attitudes of people constitute one of the problems in designing passenger compartments of automobiles. This problem is the basis for the theme of the cover design by Homer W. Mitchell, of the General Motors Styling Staff.

To answer the question of how best to provide for comfortable human accommodation in the automobile, designers at GM Styling begin with considerations of human space requirements. They develop the compartment around the human body. To complete this task successfully, they must utilize their knowledge and experience, as well as up-to-date techniques and tools. An example of such a technique currently applied in the design of all General Motors passenger cars is the GM interior comfort dimensioning system. It is a realistic system which is referenced to the human body itself. It is based on designing within dimensional limits that include most individuals rather than on the so-called "average" man. Special tools, developed by Styling Staff engineers, aid in making the measurements.

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GENERAL MOTORS ENGINEERING JOURNAL

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THE GENERAL MOTORS ENGINEERING JOURNAL is published quarterly by the Educational Relations Section of the Public Relations Staff, General Motors Corporation. It is intended primarily as a medium for presenting to educators in the fields of engineering and allied sciences the results of General Motors research and engineering developments in both the product and production fields.

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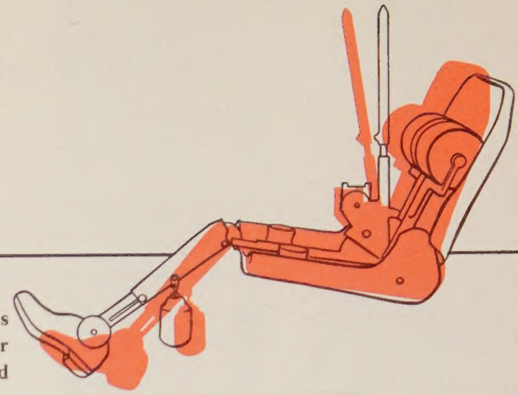
How Human Measurements Are Applied in the GM Comfort Dimensioning System



The comfortable placement of people of different sizes in the passenger compartment is a constant challenge to automobile designers. The interior space is subject to a number of influences such as user demand, aesthetic qualities of the entire car, and economic and engineering limitations. To provide for comfortable human accommodation in the car, therefore, the designer needs a knowledge of human space requirements. Secondly, he needs the help of reliable techniques for transforming these requirements into properly dimensioned drawings of a new design. Such a technique has been developed and put into use by the General Motors Styling Staff. Known as the GM comfort dimensioning system, it is based on a more realistic concept of human measurement and placement in a car. The system also includes the use of newly developed measuring tools and manikins.

Designing the automobile passenger compartment for comfortable human accommodation requires a knowledge of human space requirements. This, in turn, requires adequate data on human measurements and a means of dimensioning the interior configuration of the car. Furthermore, the dimensioning must be a realistic method which is based on the human being, his position in the compartment, his seated attitude, and his relative comfort.

The GM Styling Staff has developed and put into use in the design of all General Motors passenger cars a system which fulfills the need for designing on the basis of human comfort. This system is known as the GM comfort dimensioning system. Data and background for the system were provided by investigations of anthropometric data, examination of national driver statistics, and dynamic testing of driver and passenger seated attitudes.

Comfort is composed of two parts:

(a) attitude comfort—the degree of comfort felt by a person due to his positioning in the car.

(b) seat comfort—the degree of support that a seat provides to a person.

The GM comfort dimension system deals only with attitude comfort. However, it aids in solving seat comfort problems because it defines exactly a person's attitude from which a seat designer can design a structure to give the proper support in that attitude.

GM System Based on the Design Limit Concept

Studies by GM Styling of human measurement data have shown that it is unrealistic to attempt to select a so-called "average" man or a "proportional" man to serve as a standard size for design purposes.

Considerable anthropometric data have been accumulated since World War II by governmental and civilian organizations. These data show no evidence of using the average man in human accommodation work. In fact, one study of uniform sizes made for the military investigated the measurements of body components of 4,063 men and found that no man of the group was average[1]. Applying the same reasoning to the total driving population will show that no one person of this larger group is average.

Other investigations proved that the theory of the proportional man is not valid, at least for engineering purposes. This is the theory that the length of human limbs, torso, and head are in a certain proportion to the over-all stature height and that when the height varies the body segments will vary by the same proportion. Another study for the military showed that in a group of men whose heights averaged 68.4 in., their sitting heights varied as much as 8.6 in.—from 30.7 in. to 39.3 in.[2]. In other words, for any given stature dimension, there are individuals with long torsos and short legs, and vice versa. Thus, the proportional man cannot be used for passenger compartment design; each body segment must be considered individually.

Rather than the average man or proportional man theories, the GM comfort dimensioning system is based on the design limit concept. This states that efficient space utilization can be acquired during the design stage of a product by establishing the upper and lower limits for human variables.

This concept was developed during World War II when design engineers and anthropologists, working on human accommodation problems for military vehicles and combat aircraft, needed information on human body sizes in terms other than average[3]. Their surveys

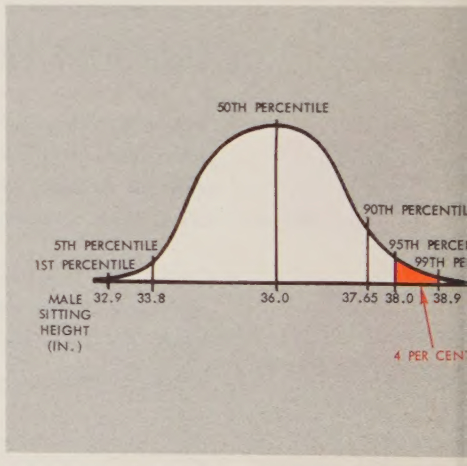


Fig. 1—This bell-shaped probability curve plots the sitting heights of a group of men and shows that more men are found in the middle ranges than at the ends. Expressed in terms of a percentile scale, this information is useful to designers since it provides a scale from which to base the minimum vertical adjustment required by a car's seat adjuster mechanism. The curve indicates that a vertical adjustment of 6.0 in. accommodates 98 per cent of the group. If the adjustment is reduced to 5.1 in., however, only four per cent of the group is affected. Applying this method to both ends of the curve, the Styling Staff found that the middle 90 per cent of the group (from the 5th to the 95th percentiles) is accommodated with a 4.2 in. vertical seat adjustment.

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A realistic way: dimension the automobile interior around the human body

showed that when considering data of a specific body segment obtained from a given test group, more persons were found near the center or the middle ranges of the segment size than at the ends. Also, the number of persons decreased rapidly toward the ends of the curve for each numerical increase or decrease in the segment size. This, of course, is the familiar bell-shaped probability curve.

The GM dimensioning system uses a percentile scale, instead of probability curves, to better express the variance in lengths of human body segments (Fig. 1).

Percentile simply means the division of a group of a single variable into 100 equal parts. If an individual is in the 30th percentile in stature, for example, he is taller than 30 per cent of the group and shorter than 70 per cent. It is more important for designers to know where a person fits into the total group than to know his absolute dimensions.

Applying the design limit concept in the GM system, the 90th percentile leg segment of the adult male is used as a standard for leg roominess. Higher percentile leg dimensions show very small increases in leg reach, for example, 0.7 in. for the 95th percentile. Consequently, the comfort difference is slight. Above a 97.5 percentile, however, comfort differences are noticeable. To accommodate the relatively small number of persons in this group, the automobile seat track can be relocated rearward.

System Recognizes Seat Depression and Body Attitude

In adopting the GM comfort dimensioning system, it was necessary to recognize the influence of a number of seat variables, as well as the influence of the human body in its seated attitude.

CORRELATION COEFFICIENTS OF SEAT DEPRESSION VARIABLES

	(r)
Seat Weight vs. Body Weight	.933
Body Weight vs. Hip Width	.794
Seat Weight vs. Seat Depression	.692
Body Weight vs. Seat Depression	.678
Hip Width vs. Seat Depression	.584
Stature vs. Hip Width	.415
Stature vs. Seat Depression	.333

Table I—This table shows the coefficients of correlation (*r*), or the degree of relationship, between several seat depression variables, based on information obtained by the Styling Staff from a sample group of 240 persons. When using correlation coefficients as indicators, a coefficient of + 1.00 describes the relationship between two perfectly correlated variables, a coefficient of 0.00 indicates there is no relationship, and a coefficient of − 1.00 shows an inverse relationship. According to Day[4], coefficients above 0.700 indicate significant relationship between variables.

The prime function of the automobile seat is simply to support the passenger in the desired position. This support, or provision for anatomical and psychological comfort, while not significant in space allocation, does create spatial problems for designers.

The depression of the automobile seat by the human body is important to designers when allocating space. An increase in seat depression, for example, reduces vision of the roadway and increases head clearance by lowering the occupant. This, in turn, can cause seat-to-underbody tunnel interferences as well as a decrease in leg room.

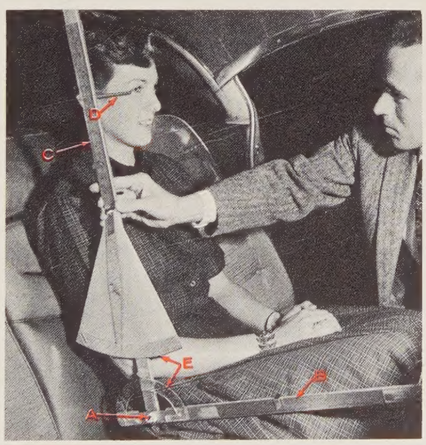


Fig. 2—This is the sitting attitude checking device constructed by the Styling Staff to determine body segment locations of automobile drivers and passengers. After each person in the test group assumed a comfortable sitting attitude by using the seat adjuster mechanism, probe *A* was centered over the hip point. The horizontal measuring arm *B* was then adjusted to the center of the knee joint and the vertical measuring arm *C* was adjusted until the eye level rod *D* was pointing to the center of the eye. Readings in degrees then were taken from protractors *E* of the eye line tilt (the angle between the eye and the hip point) and the angle between the torso line and the thigh (an imaginary line between the hip point and the center of the knee joint). The vertical and horizontal linear measurements in inches also were recorded.

Different depressions of a seat are affected by three variables: (a) the weights of people, (b) the seated attitudes of people, and (c) the seat design attitude. To define the interrelationships of these variables, GM Styling studied a group of 240 men and women, carefully chosen as representative of the nation's driving population. These people were tested on a specially constructed seating platform to determine the effects of the human body on a seat. Relationships between stature, weight, hip width, and seat depression were evaluated after the raw data were processed by computers. Findings showed significant correlation between body weight and hip width, and between seat weight (that percentage of body weight imposed on the seat cushion) and seat depression (Table I). Further analysis of this information indicated that 47.8 per cent of the seat depression for this group was due to the sole effect of seat weight.

To find out what sitting positions gave proper body support and relief from fatigue—two important requirements for comfortable and safe driving—GM Styling also checked the sitting attitudes of a sample group of people in driving positions (Fig. 2).

Data from the tests indicated that most persons adjust to similar seated attitudes by using the seat adjusters. In other words, the physical seat establishes the posture of drivers and passengers. Since data from a previous study indicated that seat weight was a percentage value of the human body weight and that seat design governed this percentage of weight transfer to the seat cushion, it was concluded that both the human seated attitude and the seat attitude are controllable factors in passenger compartment design.

The above data on the influence of seat variables and the human body were applied in the development of a three-dimensional manikin, which is described later in this paper.

Dimensions Referenced From Human Hip Point

A prominent part of the GM dimensioning system is the reference point on the human body. This reference point is the bony protrusion of the thigh bone (trochanter), which represents the center

of the hip joint (Fig. 3). It is designated the *H* point for reference dimensioning. It offers a well-defined, easily located point for dynamic testing, and its relative position is not affected by changes in torso posture or leg attitude. Dimensions that define torso room and entrance clearance are examples of those measurements that are particularly well-referenced from the *H* point. Use of the *H* point for reference allows more realistic dimensioning for human comfort than is possible with the system based on the *A* point. The *A* point, used throughout the automobile industry for many years, is a point on the car seat rather than on the human body.

Specially Built Manikins Aid Layout and Checking

To apply the design concept of the GM comfort dimensioning system properly, designers use two- and three-dimensional manikins. These devices simulate various sizes, weights, and attitudes of the human

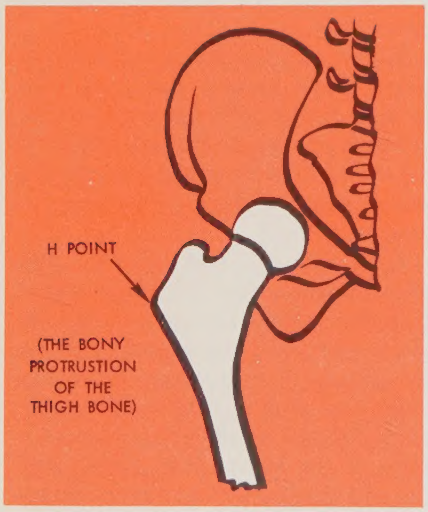


Fig. 3—The *H* point, or hip point, is the designated reference point on the human body for the GM dimensioning system. It is the practical hinge center for the torso and thigh and is easily located on the body.

body to help in the study of passenger accommodation problems. They also serve as tools for checking seating bucks and measuring interior space in automobiles.

In developing the three-dimensional manikin, the degree of seat depression was based on the 50th percentile adult male weight. This weight, which is 167 lb, determines the mean depression of the seats. In tests run with variable loads on various designs of seat construction, it was found that with the addition of 30 lb to the seat pan contour, an average increase of one-quarter inch was noted in the seat depression. If the seat spring rate is assumed to be constant, driver weight data can be projected to develop

BODY WEIGHT - SEAT DEPRESSION COMPARISON

BODY WEIGHT	WEIGHT PERCENTILE		CHANGE IN HEAD CLEARANCE DUE TO SEAT DEPRESSION (IN.)
	MALE	FEMALE	
227 LB	98.9		+ 0.50
197	87.5		+ 0.24
167	50.0	92.5	0.0 Mean Depression
137	12.5	56.4	- 0.24
107		13.4	- 0.50

GM DIMENSIONING STANDARD

Table II—This comparison of body weight and seat depression shows the change in head clearance due to a change in the occupant's weight on the seat. In the GM interior dimensioning system, the amount of seat depression is based on the 50th percentile weight of the adult male, or 167 lb. At this weight level, 92.5 per cent of the females will sit higher than the 50th percentile weight male. This is an aid to women drivers, since anthropometric data show that the average seated eye height of the female is 2.1 in. less than that of the average male driver.

an analysis of body weight and seat depression. This, in turn, provides information on head clearance (Table II). This analysis shows that the 92.5 percentile female weight is equivalent to the GM weight standard. Accordingly, 92.5 per cent of the females will sit higher than the 50th percentile male. This is an aid to the women drivers, since the average seated eye height of the female is over two inches less than that of the average male driver.

The choice of the weight standard for the three-dimensional tool is believed to be a sound one for two important reasons. First, the industry's seat designers have traditionally worked with the 50th percentile male weight as the depression standard and are completely familiar with its ramifications. Secondly, it was found that the depressions of a seat for the male driving population are distributed according to the probability curve function. Using the weight of the mid-range of this curve defines the seat depression for the largest number of men, which in turn defines more accurately the height clearances in the compartment.

Additional data on which the design of the manikin was based were obtained from a study of eight men who met the standards of 90th percentile height and 50th percentile weight. A GM Styling measuring tool, the anthropometer, was used to make a check of the depressed contour of each individual (Fig. 4). Seventeen points along the centerline of the back and thigh determined the position of each person. The person who best represented the contours was chosen for the development of the depressed contour.

Using a standard production seat in normal car position, a plaster cast was taken of the selected person in the driving attitude. Hip and knee joints were referenced by placing nails in the wet plaster at the appropriate locations. A rough male mold, taken from the original plaster, was corrected for slight voids and a new master female model was cast. Drawings of this master model were used as the basis for modeling in clay the male seat and back pan contours for the three-dimensional manikin.

To determine the length of the 90th percentile leg segments, link dimensions of the 90th percentile adult male tibia and femur were used, along with the locations of the depressed contour hip and knee of the selected person[5]. A shoe contour of the 90th percentile foot (size 10½ EE, according to U.S. Army and civilian shoe schedules) finished the basic outline of the three-dimensional manikin[6]. This manikin was built by the GM Engineering Staff.

Other items added to complete the manikin (Fig. 5) were:

- Comfort angle scales for each body segment joint and the back pan
- Adjustable links for the tibia and femur segments
- A graduated sliding probe for measuring torso accommodation
- Spirit levels to orient the manikin in space
- Weights for each body segment.

A two-dimensional manikin also was developed for use during the initial stages of passenger compartment design.

The Appendix to this paper describes how designers at the Styling Staff apply the principles and the tools of the GM comfort dimensioning system.

Conclusion

This dimensioning system is now being applied in the design of all GM passenger cars. More than 50 two-dimensional manikins and 19 three-dimensional manikins currently are in use in various GM Divisions for development and checking purposes. Experience with the system shows that it provides:

- A realistic and simplified method of passenger compartment design reflecting human space requirements in an automobile
- A fast and accurate verification of human accommodation requirements in seating buck proposals and in production cars
- A realistic basis for comparing different passenger compartment dimensions.

Of course, the standards of human dimensions used in the system will undoubtedly change in the future as the

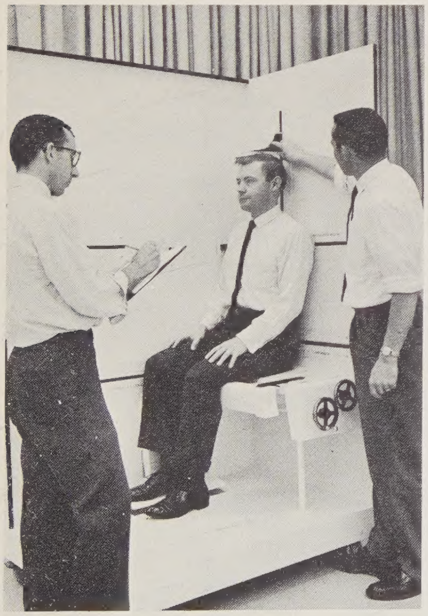
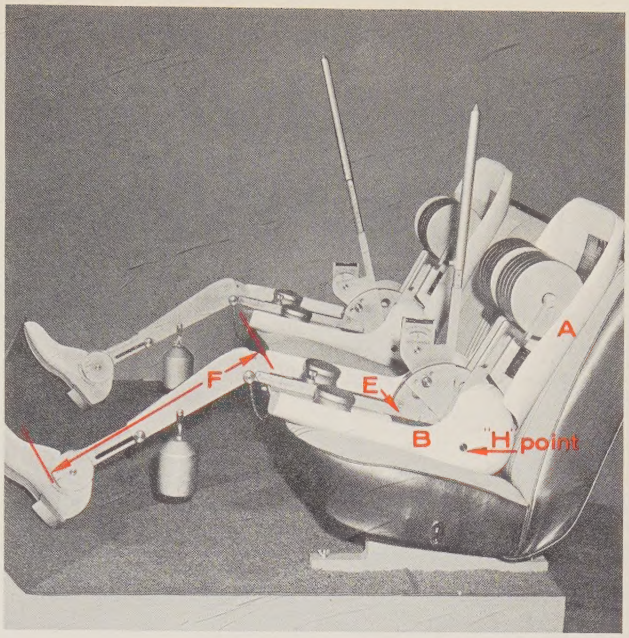
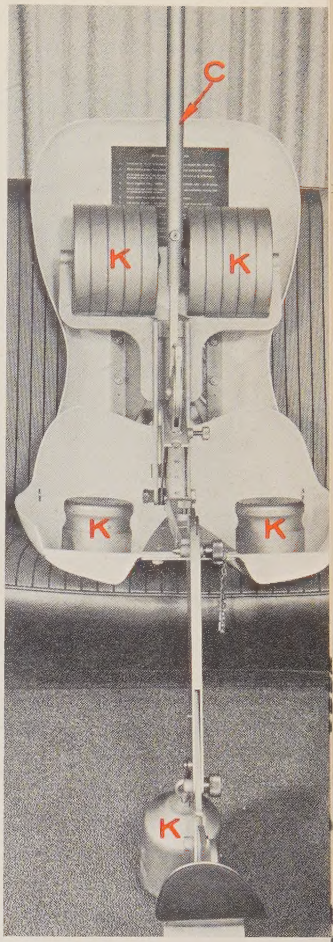
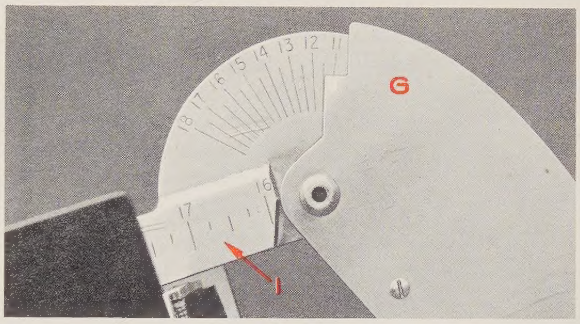
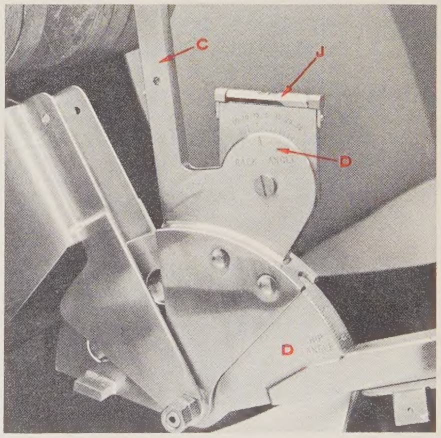


Fig. 4—The GM Styling anthropometer, shown above, is an accurate measuring tool for measuring body segments. The device was used to find the percentile lengths which ultimately became the basis for the size of a three-dimensional manikin used in the dimensioning system.









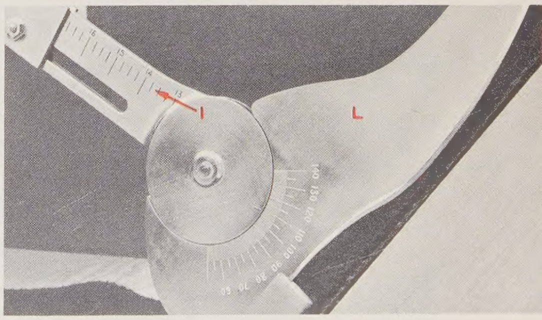


Fig. 5—This three-dimensional manikin (upper left) designed by the Styling Staff and constructed by the GM Engineering Staff, represents the weight, length, and contour of a selected adult male driver (90th percentile height, 50th percentile weight). Constructed of glass fiber and metal, the manikin exerts the same pressure and takes up the same compartment space that a human of the same size and weight does. The device consists of a separate back pan *A* and seat pan *B* mechanically hinged at the hip, or *H* point, which simulates the actual pivot center of the human torso and thigh. A graduated sliding probe *C* is hinged from the *H* point to measure the head and torso room in the compartment. A quadrant *D*, calibrated in degrees, is fastened to the probe and is used to measure hip and back angles. A square steel tube *E* attached to the seat pan establishes the 90th percentile femur segment and serves as a base line for angular measurements. The lower leg segment *F*, corresponding to the 90th percentile tibia segment, is connected to the femur link at *G* where a degree scale measures the knee angle. At the end of the lower leg segment a metal foot *L*, complete with shoe sole and heel, is pivoted at the ankle permitting a movement from 60° to 140°. The femur and tibia links have adjustments *I* to facilitate any changes that might have to be made as a result of future changes in human body dimensions. Spirit levels *J* help orient the device in space. Body segment weights *K* are placed at the proper center of gravity locations to bring the manikin's weight to 167 lb, which corresponds to the 50th percentile weight of an adult male in the GM interior dimensioning system. At the upper right is shown the front view of the manikin with the weights in position.

knowledge of anthropometry increases. Human dimensions, therefore, will be constantly reviewed and appropriate corrections placed into the system. The manikins are designed so that these changes can be incorporated without modifying the basic procedure.

Bibliography

1. HERTZBERG, H. T. E., *Some Contributions of Applied Physical Anthropology to Human Engineering*, Annals of The New York Academy of Sciences, Volume 63, November 1955.
2. NEWMAN, RUSSELL W., and WHITE, R. M., *Reference Anthropometry of Army Men*, Report No. 180, Environmental Protection Branch, Quartermaster Corps, United States Army, 1951.
3. CHAPANIS, A., *The Design and Conduct of Human Engineering Studies*, Technical Report No. 14, Project NR 143-075, San Diego State College Foundation, San Diego, California, July 1956.
4. DAY, EDMUND E., *Statistical Analysis* (New York: The Macmillan Company, 1952).
5. DEMPSTER, W. T., *Space Requirements of the Seated Operator*, WADC Technical Report 55-159, Aero Medical Laboratory Contract No. AF 18 (600) 43, Dayton, Ohio, July 1955.
6. . . . *Facts and Figures on Footwear*, National Shoe Manufacturers Association, 342 Madison Avenue, New York 17, New York, 12th Edition, 1958.

GLOSSARY OF HUMAN ACCOMMODATION TERMS

H Point - - - The main reference point on the human body in the dimensioning system. It is located at the upper end of the femur, the bony protrusion of the thigh bone.

Back Angle - - - The angle of the seated human torso in relation to the vertical position. Range: 20 to 35 degrees.

Hip Angle - - - The angle between the torso and thigh; the main attitude comfort angle determining passenger compartment space. Range: 75 to 110 degrees.

Knee Angle - - - The angle between the thigh and lower leg. Range: 75 to 120 degrees.

Foot Angle - - - The angle of the bare foot in relation to the lower leg. Range: 75 to 120 degrees.

Torso Room - - - The dimension from the *H* point to the inside roof of the car on an 8° reclining angle plus 4 in. (to compensate for the variations in the depressed contour of the manikin). This dimension defines the amount of room provided for the occupant's head, torso, and other necessary clearances.

Application of the Dimensioning System

THIS Appendix presents information on how the GM comfort dimensioning system is applied in the design of an automotive passenger compartment. For purposes of discussion, the compartment design for a four-door sedan will be presented.

This system can be used without any prior knowledge of the automobile's components, although in practice, the GM car Division's management normally determines the car's wheelbase, tread, and overall width. Division engineers lay out the chassis, which includes the body frame, engine, transmission, and suspension system. They also design the underbody to clear the chassis structure and the drive-train components.

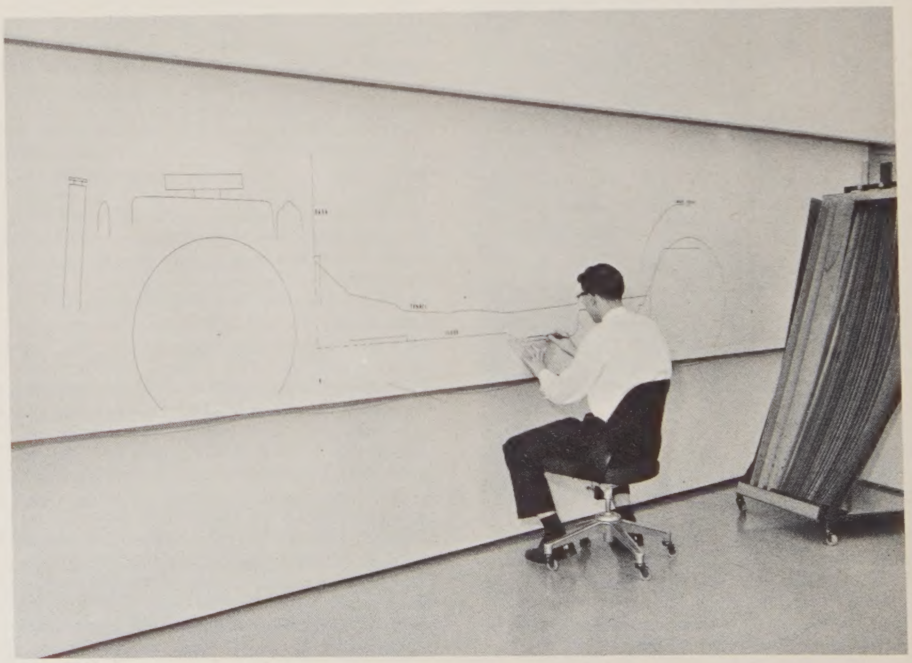
This information is important to the design of the passenger compartment because the location of the engine determines the position of the dash, which defines the forward boundary of the compartment. The location of the drive train components, transmission, propeller shaft, and rear axle establish certain height and length controls on the compartment design, limitations which also are important.

The GM Styling designer begins his work by transferring these principal dimensions and component locations to a full size, gridded vellum drawing on which the initial design is developed (Fig. 1A). He then provides room for floor carpeting and dash liner.

Comfort angles for the foot, back, and hip are locked in place on the two-dimensional manikin, and the device is placed on the drawing with the foot on the dash line (Fig. 2A). These three comfort angles, along with the knee angle which is a function of the sitting height, are used to determine the most comfortable position, or attitude, for occupants of a given automobile size or configuration. These angles tell the designer whether the compartment lacks space or if the available space is not being efficiently utilized. Standards for these comfort angles are based on anthropometric studies of body segment angular ranges and on investigations of prior production cars with the three-dimensional manikin.

The designer next draws a clearance line *A* over the front tunnel to represent room for the depressed seat cushion and seat jounce (Fig. 2A). To determine the location of the occupant, he holds the manikin's foot on the carpet line, and shifts the manikin along line *A* until the vertical grid on the manikin aligns with the vertical grid on the drawing (Fig. 2A—inset).

The toeboard connecting the dash and the underbody is drawn in place in relation to the foot angle (Fig. 3A). Point *B* on the roof headlining is marked on the 8° reclining angle line drawn from the



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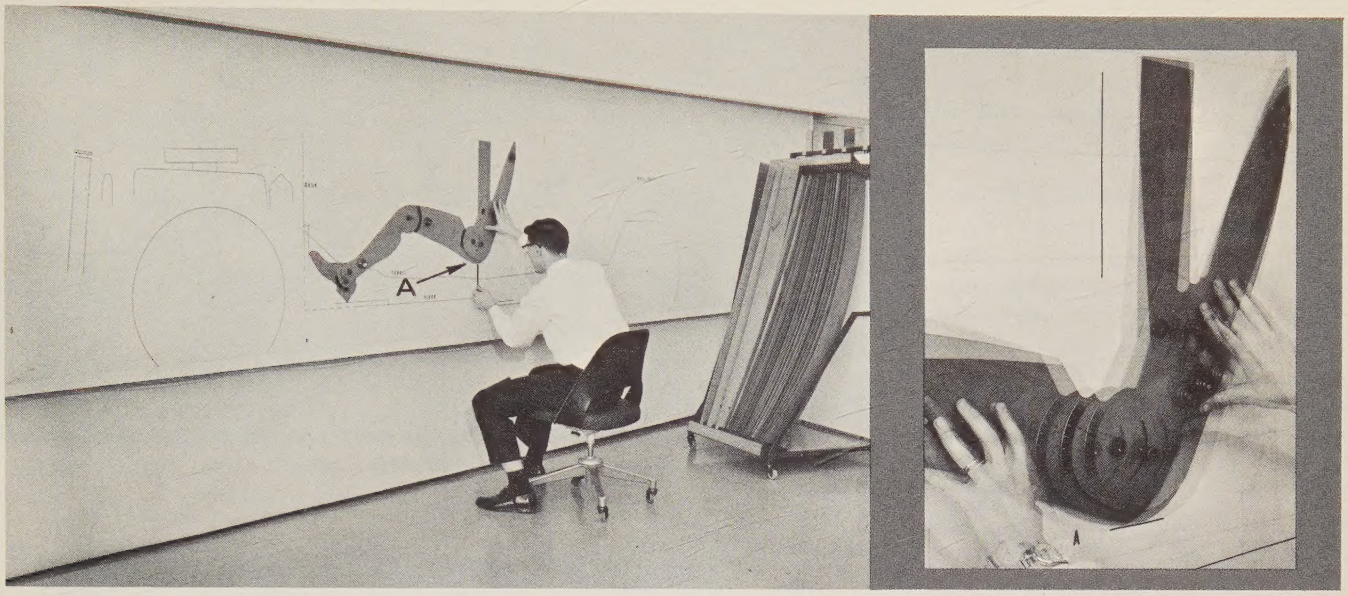
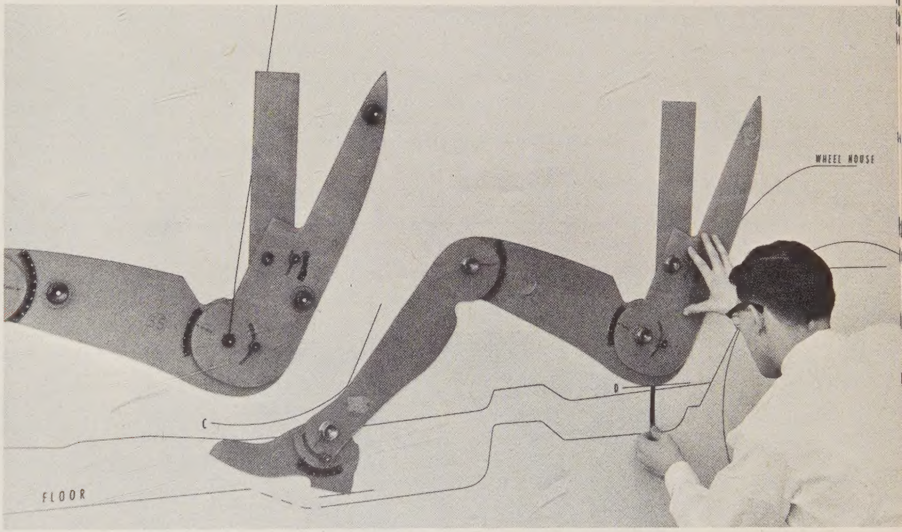


manikin's *H* point. This dimension defines the amount of space provided for the occupant's head and torso. Line *C* shows the front seat clearance requirements.

Comfort angles then are selected on the manikin for the rear passenger compartment and the dimensioning procedure is repeated (Fig. 4A). In designs where the transmission tunnel does not exist, a clearance dimension from the underbody to lines *A* and *D* is substituted.

Point *E* is marked next to establish the rear torso room requirements (Fig. 5A). This step completes the basic passenger compartment design. Following this, the

4A



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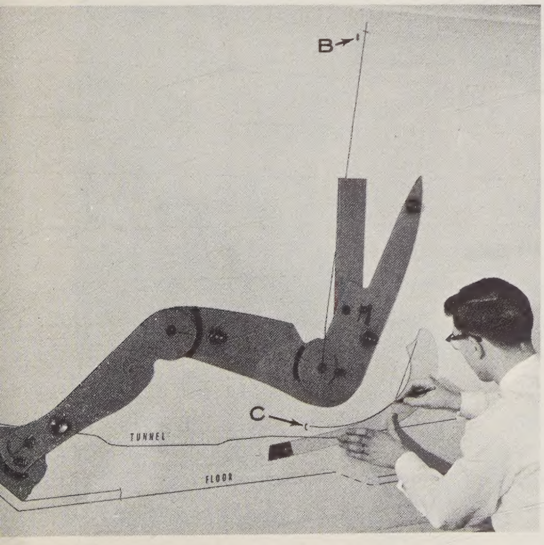
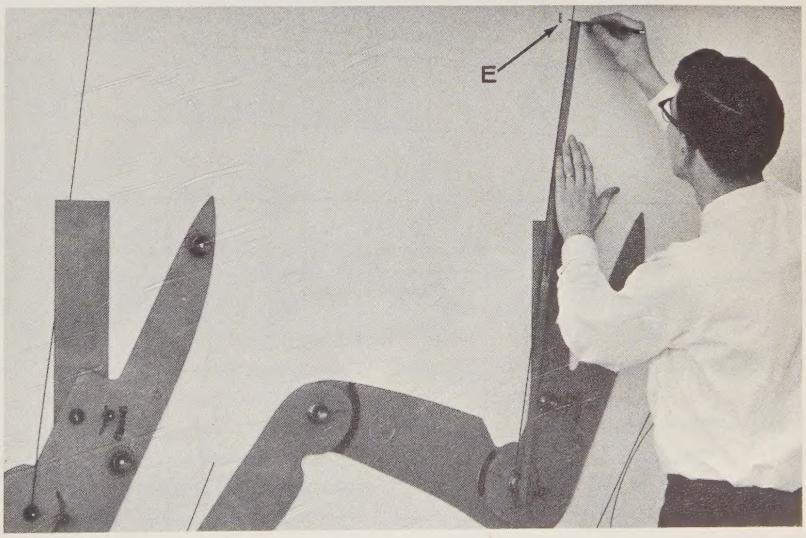




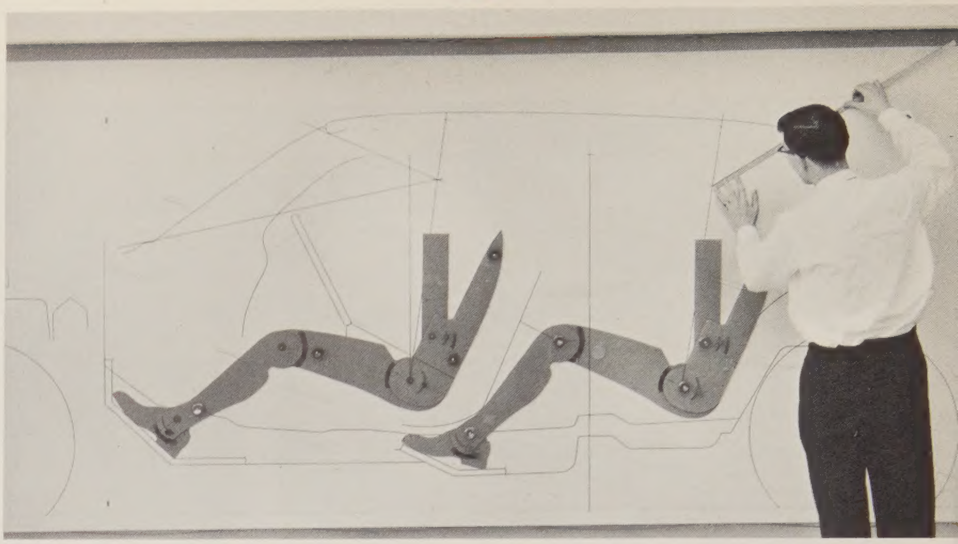
5A

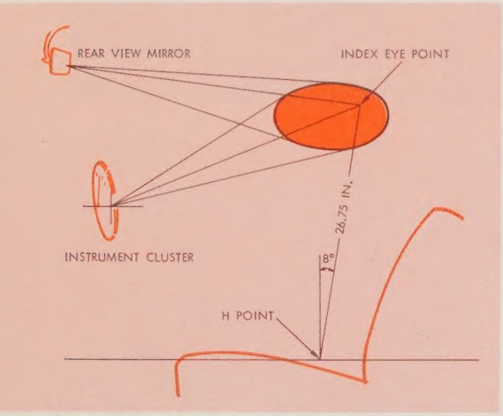
design of the exterior configuration of the car can proceed.

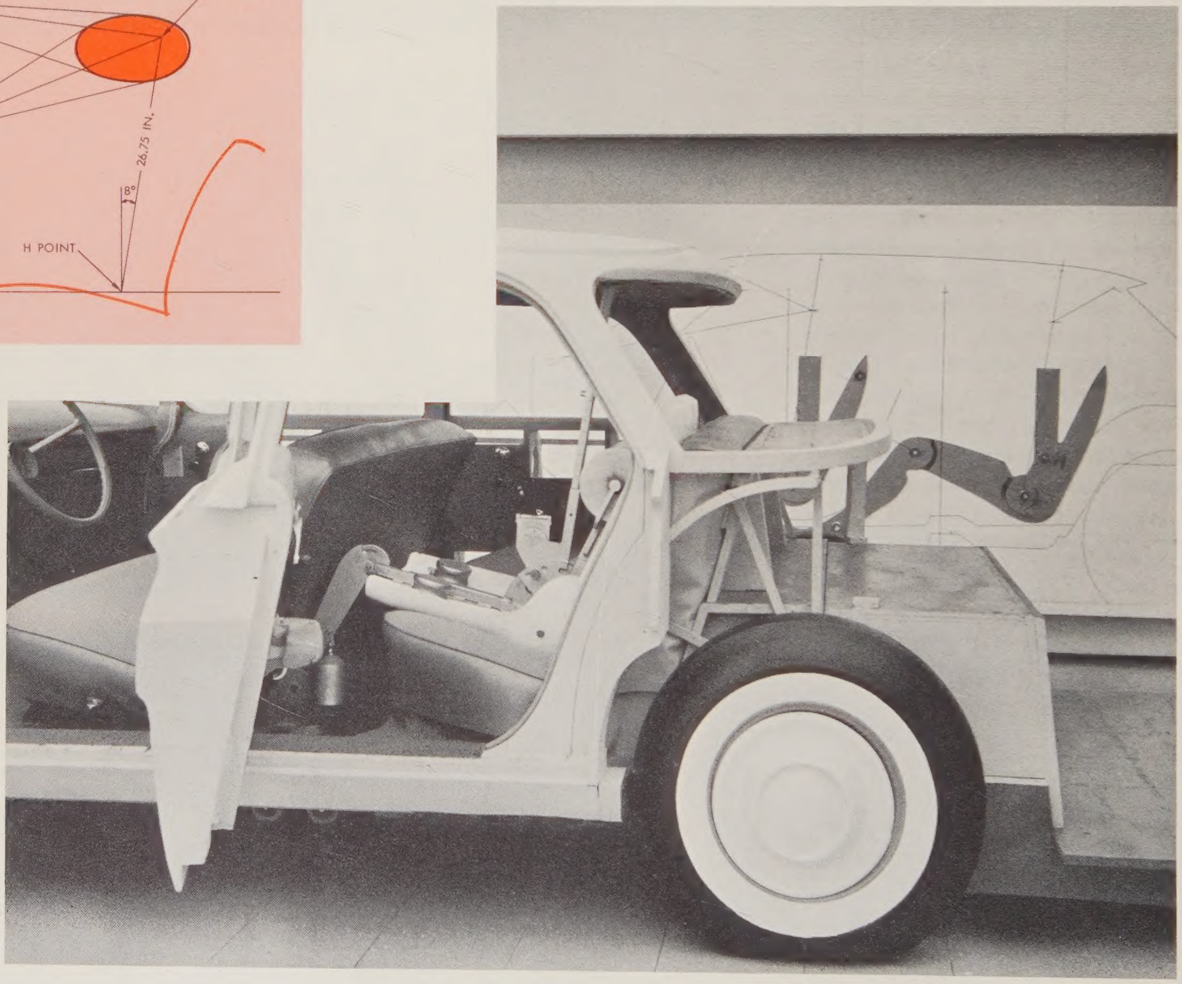
Certain other compartment dimensions also are important as the design progresses. Entrance conditions, location of the steering wheel and driver controls, and vision requirements are placed on the drawing in relation to the occupants (Fig. 6A).

The location of the eyes of different drivers, for example, will vary in a passenger compartment because of differences in seat adjustment and differences in a driver's posture, sitting height, and eye height. To account for these variations the designer uses a template, based on an eye range scale shown in the following diagram, to locate the instrument

6A





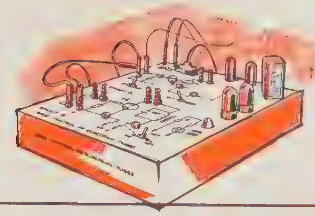


7A

cluster and rear view mirror. The eye range scale, which takes into account the total range of eye positions, is based on an index eye point located 26.75 in. from the *H* point on the 8° reclining angle.

Finally, to verify the design, the dimensions from the drawing are transferred to a full size seating buck of the proposed sedan (Fig. 7A). Constructed of wood, glass fiber, and metal, the buck is a three-dimensional representation of the car. Doors, window sills, pillars, and other structural components are included to depict actual entrance, exit, and seat conditions. These conditions are verified by using the three-dimensional manikin, shown here in the rear passenger compartment.

New Teaching Aids Applied to Electronics Laboratory Experiments



By CHRIS A. COMMON
General Motors Institute

A problem in operating a laboratory for instructional purposes is how to minimize the time that students spend in setting up equipment. General Motors Institute recently reduced the time formerly needed for setting up electronics experiments by using a newly developed, self-contained chassis. All of the required components to be used in an experiment are permanently mounted and wired on the chassis. Students no longer must spend time assembling resistors, capacitors, inductors, leads, wires, tubes, and other equipment before beginning an experiment. No longer is it necessary to check for loose connections or misplaced leads. The unit is ready to use as soon as the student applies the correct power and selects the appropriate instrumentation for his investigation of the circuit. In addition to reducing set up time, the self-contained chassis helps beginning students gain a better understanding of the circuit.

New aids reduce time required to set up experiments

Since the early 1900's the scope of engineering education has been broadened many times. Many changes have been made in engineering curricula to meet the continual advancements of scientific knowledge and technology. Although the engineering student of today is exposed to a broader course of subject material than his counterpart of fifty years ago, the time alloted to his training has remained the same in the majority of engineering colleges. This situation has caused many engineering colleges to embark on a variety of programs to meet the challenge of making the most out of the time available for instruction. At General Motors Institute, for example, the problem of optimum utilization of available instruction time has been quite pronounced because of the intensive nature of the cooperative engineering program.

There has been a considerable amount of discussion as to the need for laboratory work in an engineering curriculum. Some people have proposed minimizing or eliminating engineering laboratory work to provide more time for classroom discussion. General Motors Institute, however, has always believed that laboratory work is important. The laboratory teaches the experimental method and provides meaningful experiences which are a necessary part of an engineering education. The laboratory also provides a student the opportunity to observe phenomena and helps him to understand and appreciate classroom work. Finally, the laboratory provides the opportunity to test theories, to conduct experiments which will give essential data, and to interpret experimental results.

Laboratory work at General Motors Institute is aimed at achieving the following goals:

- Make the most of the time available for the laboratory period
- Make the laboratory experience understandable to the student
- Correlate the laboratory experience with classroom theory to give the student a better working knowledge of the subject material.

One way in which these goals are achieved is by the use of various teaching aids which have been developed by G.M.I. faculty members to meet specific needs in the laboratory[1,2]. One of the latest of these aids is used in electronics laboratory work.

Too Much Time Required to Set Up Experiments

Prior to the fall of 1960, the experience of G.M.I. in electrical engineering laboratory work was primarily in instructing mechanical engineering students in the subjects of electrical circuits, a-c and d-c machinery, electronics, controls, transistors, instrumentation, and electrical servomechanisms. Since then, an electrical engineering degree program has been in effect. The first B.E.E. degrees will be granted in the summer of 1963.

The experience gained in the past operation of the electrical engineering laboratory was used to plan the laboratory program for the new electrical engineering curriculum. The objective of the program was to make optimum use of the time devoted to laboratory work. This was especially true for the electronics laboratory phase.

Electronics laboratory experiments are somewhat unique. For even the most basic circuits and devices, many components must be assembled for a given experiment. The early operation of the G.M.I. electronics laboratory had the familiar "rat's nest" type of experiment set-up (Fig. 1-top). Here, an assortment of resistors, capacitors, inductors, tubes, wires, and meters had to be assembled by the student, with perhaps the aid of a laboratory assistant or the instructor, before an experiment could begin. The same color generally was used for all the wires. The student either could assume the circuit was correct or could painstakingly trace out the circuit.

It can be argued, perhaps, that the student is in a learning process as he traces out a circuit. The objective of electronics laboratory work in an engineering curriculum, however, is not to teach the student how to trace out wiring or find what connection is loose or shorting out. Rather, the objective is to have him obtain data to verify theories and, when this is done, to examine the experiment in detail and ask questions to make sure that he has a complete understanding of the concepts involved. This requires that a minimum amount of time be spent in placing a circuit into operation.

The disadvantages of the early G.M.I. electronics laboratory set-up were: (a) set-up time was excessive, (b) the circuit

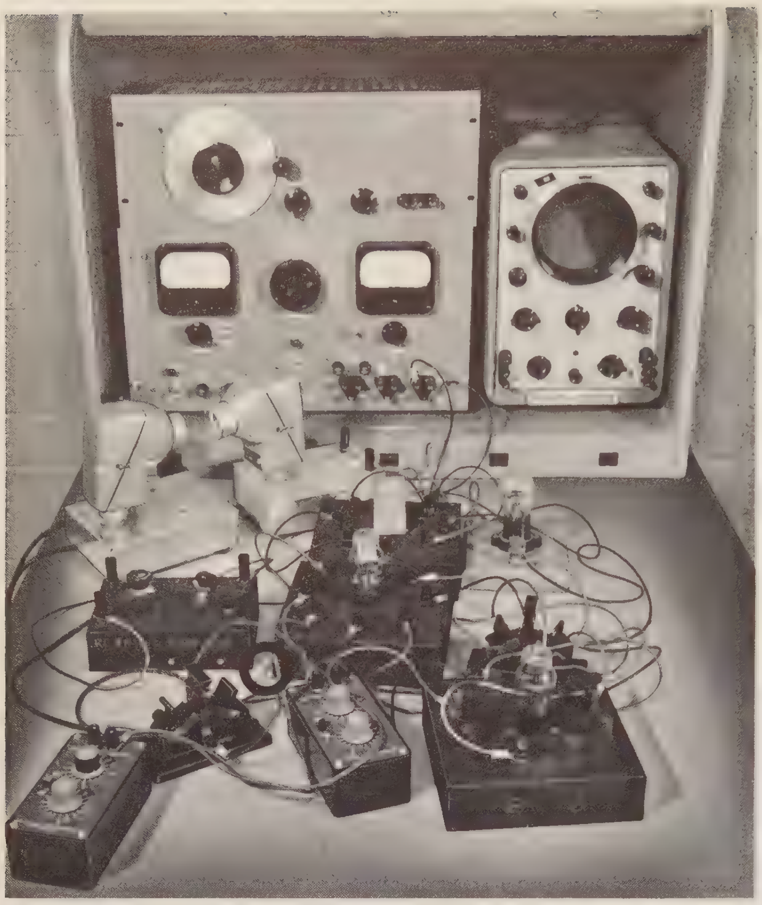
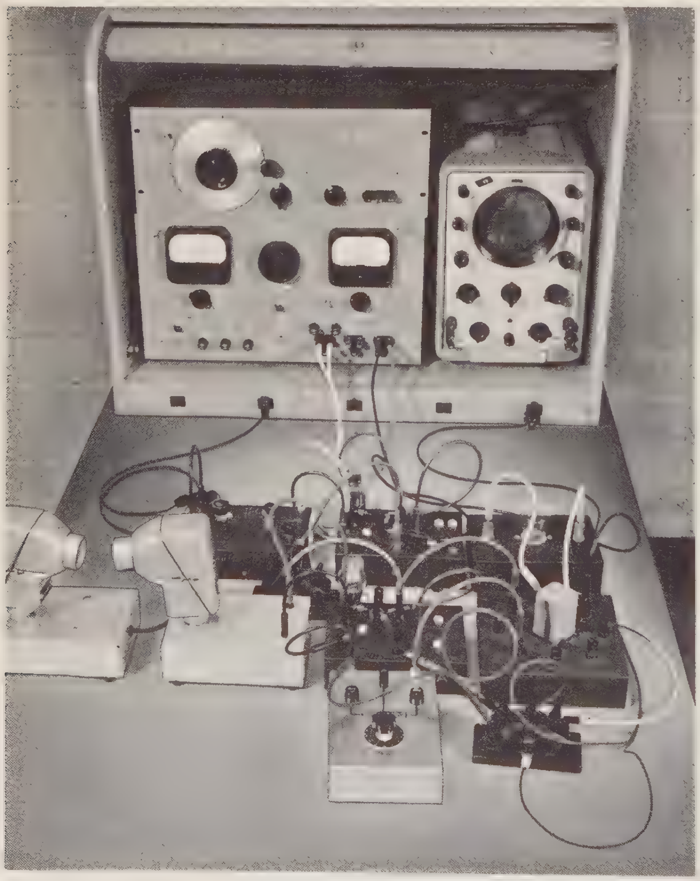


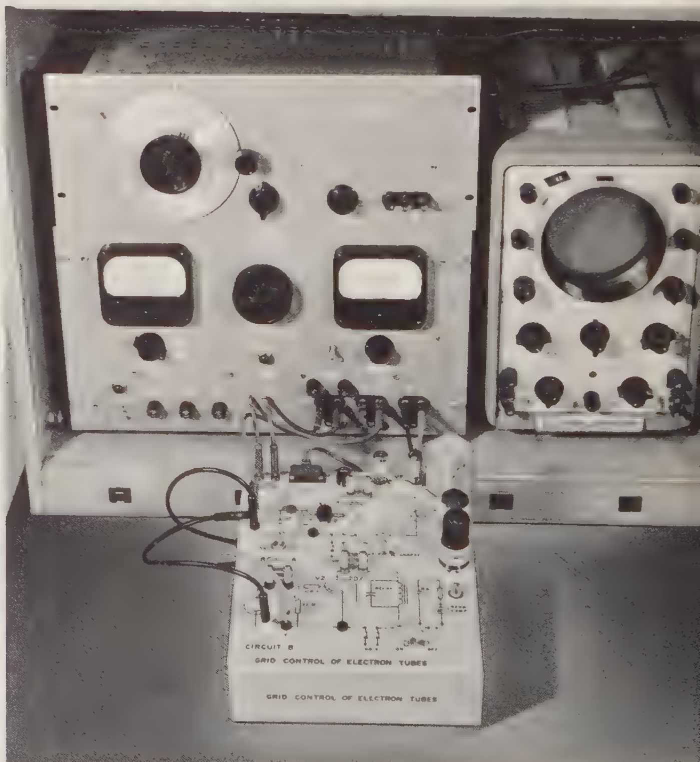
Fig. 1—These three photographs illustrate the changes made by General Motors Institute in establishing a different approach to electronics laboratory experiments. The object was to eliminate excessive set-up time and to allow beginning students to obtain a better concept of the circuits being studied.

The upper left photograph shows the typical "rat's nest" type of experimental set-up first used in the G.M.I. electronics laboratory. Spade-type leads and tube mounting chassis were used. The time required to set up an experiment was excessive and the circuit under study was not readily apparent unless time was taken to trace out the circuit. Also, there always was the chance for problems to develop caused by a loose lead, such as that shown in the photograph.

This approach was modified by using a set-up which presented a circuit layout approximating that discussed in the classroom. The experimental layout took on a little more order, as shown in the lower left photograph. Tube-mounted chassis were used and resistors were mounted to the chassis by screw-type banana plugs. The leads were color coded to give students a better understanding of where various circuit reference points were located.

The final approach is shown in the photograph below. Chassis are used which are self-contained, except for power and instrumentation. A complete schematic diagram of the circuit being studied is reproduced on the top of the chassis. Very few external connections are needed. Jacks are provided to monitor any necessary voltages. Shorting bars are in the circuit where milliammeters may be inserted.





under study was not apparent to the student unless time was taken to trace out the circuit, (c) circuit problems developed as a result of long or misplaced leads, and (d) too much time was spent checking circuits and correcting minor faults.

To overcome some of these disadvantages, a different approach was taken which was based on presenting to the student a circuit layout which approximated that discussed in class. Standard chassis were used upon which were mounted tube sockets and various basic components to be used in the experiment (Fig. 1-center). A schematic diagram of the tube circuitry was penciled on the chassis. Jacks were provided to enable the student to make connections to any of the tube elements. Standard size resistors and capacitors were connected into the circuit by putting these components on screw-type banana plugs. Colored plug-type leads, such as red for high voltage and black for ground, also were used.

This approach worked well when the proper placement of parts by the student was made so as to have a systematic parts layout. Still there were some disadvantages. Set-up time remained excessive. The students had a tendency to follow the furnished wiring diagram too closely and usually they did not readily grasp the function of the overall circuit. Also, the students and instructors spent too much time in checking the various items which can prevent proper circuit operation. Finally, components were subjected to a high rate of wear and tear when they were placed on or taken off the banana plugs.

It is acknowledged, however, that this approach would be acceptable for individual student projects or for developmental work, since the person putting the circuit into operation would be most familiar with it. Also, the flexibility of the arrangement allows the components to be changed easily.

Self-Contained Chassis Now Used

Based on the experience gained from the two previous approaches for operating the electronics laboratory, a new approach was introduced in the 1961 spring semester.

The present approach is to use chassis which are self-contained except for power and instrumentation (Fig. 1-bottom). The required circuit for the experiment is marked clearly on the top of each chassis. Jacks are provided on the top of the chassis for applying power, inserting ammeters, or as convenient access points. The jacks are color coded according to industry standards—for example, blue for plate and green for control grid. The component parts are wired onto the chassis by using the colored jacks as standoff points.

The only components that appear on top of the chassis are tube sockets, jacks, tubes, transistors, or control knobs for potentiometers. When 110-volt, 60-cycle operation is necessary, television-type interlock connectors are used as a safety precaution. Fuses are provided when adequate protection is not available at the power source.

Many experiments in an electronics laboratory require a change in components to observe the effect on circuit operation. Components are changed easily on the self-contained chassis by having switches or inexpensive movable leads permanently wired into the chassis. The movable leads give the students a better understanding of what components are being changed.

The chassis can be stored neatly on dispensing shelves (Fig. 2). All that is required on the student's part is to obtain the chassis designed for a particular experiment from the dispensing shelf and take it back to his work station.

Since the self-contained chassis have been used in the electronics laboratory, the following advantages have been noted:

- Experiment set-up time is greatly reduced over that formerly required
- Time spent by the instructor in checking out circuits before power is applied is practically nil
- Students obtain a better concept of the circuit being studied
- Broken parts are reduced to a minimum
- Students have time to study a circuit after data have been taken.

Although a student does not connect a major part of the circuit, he does have to apply the correct power to the circuit and he does have to investigate the operation of the circuit with appropriate instrumentation.

Finished Chassis Simple to Build

Bare chassis, made of aluminum, are purchased in a painted condition. All wiring and mounting of components required for a finished chassis are done at G.M.I*. The size of a chassis is determined by the room available for the easy mounting of larger components such as chokes and transformers.

Once the chassis size is determined, an inked drawing is made of the circuit diagram to be used on the chassis. A silk screen (also a purchased item) then is made directly from the drawing and the diagram is transferred onto the painted chassis. Holes are drilled in the chassis and the required components are mounted and wired to complete the operation (Fig. 3).

It is possible to purchase chassis complete with components and all required wiring. However, if a specific circuit is desired which is not a standard produc-

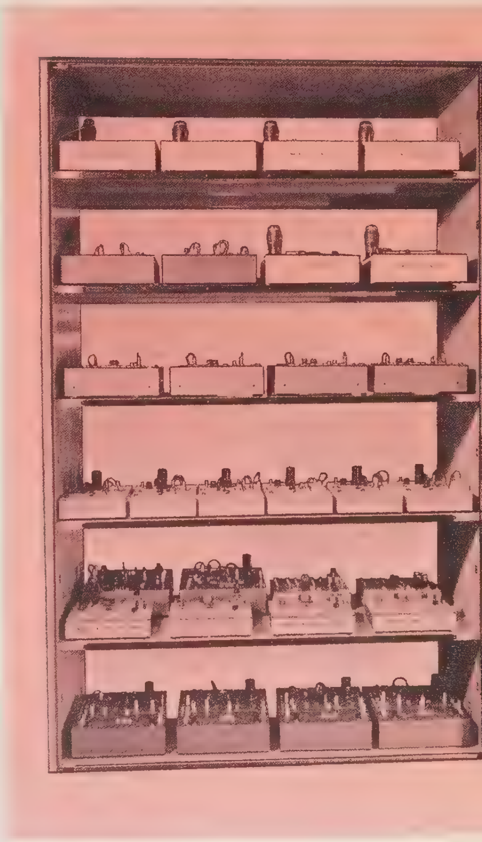


Fig. 2—Chassis for various electronics experiments are stored on dispensing shelves in the laboratory area and are readily accessible.

*Engineering educators interested in obtaining further information on the self-contained chassis as an electronics laboratory teaching aid may write to General Motors Institute, Electrical Engineering Department, Chevrolet at Third, Flint, Michigan.

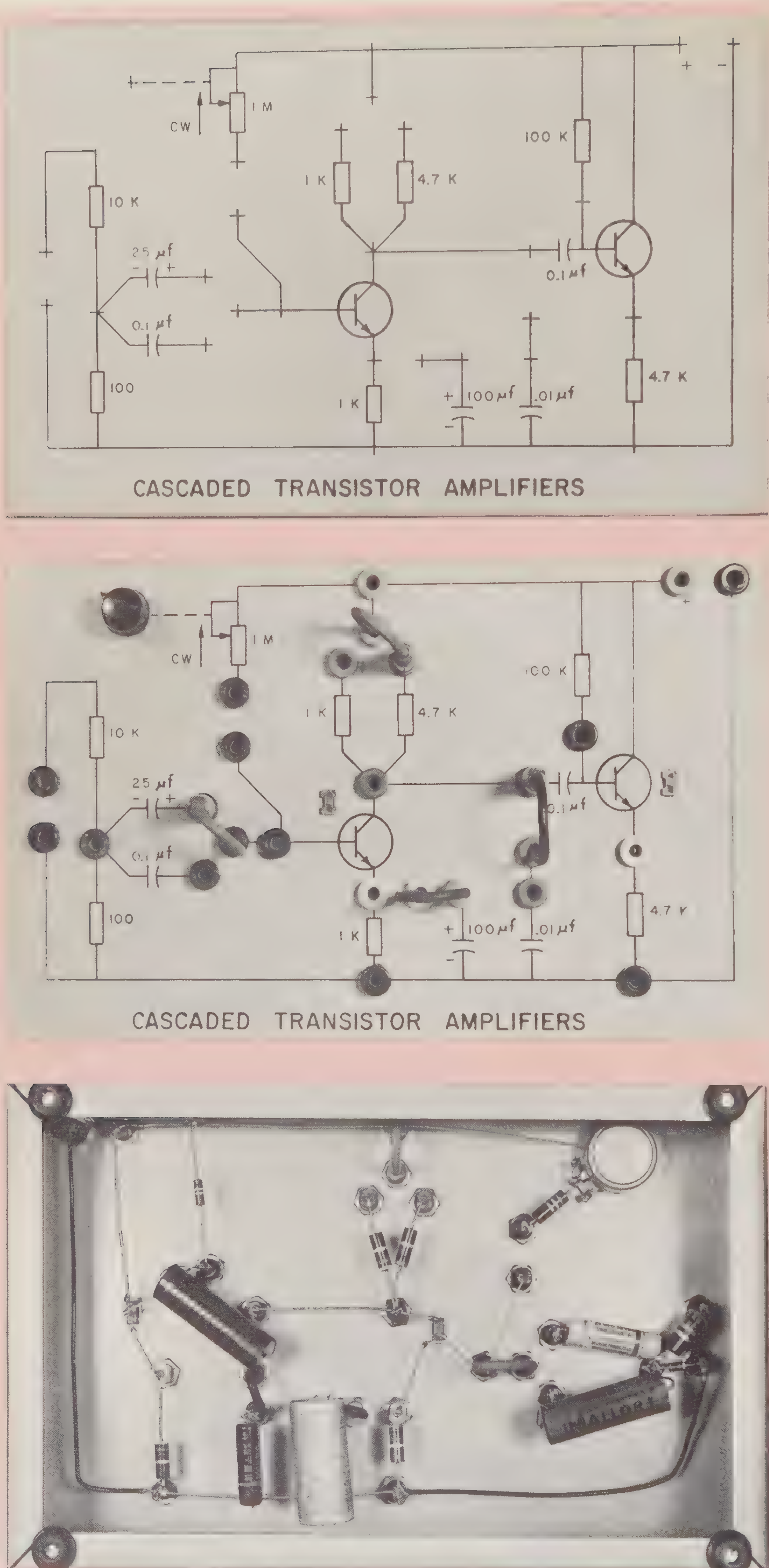


Fig. 3—The circuit diagram is transferred onto the painted surface of a chassis by the silk screen process. Crosses on the diagram indicate where holes are to be drilled (top). After the holes are drilled, the required components are mounted (center). Various components may be placed in or out of the circuit by changing a movable plug from one jack to another. All jacks are color coded to follow industry standards, for example yellow for emitter and green for base. The wiring procedure is kept as simple as possible. The undersides of all chassis are kept open so students may examine the wiring and components used (bottom).

tion item, the cost per chassis will be higher. General Motors Institute has found it more economical to purchase bare chassis and then complete the remaining work itself.

Conclusion

The electronics laboratory classes at General Motors Institute are limited to 12 students, with two students per work station. Under this procedure, six chassis are required per laboratory class. The savings in laboratory set-up time, the minimum of replacement parts needed, and the improvement in student understanding of the circuits have made the project well worth while.

Bibliography

1. Trathen, Wesley J., "The Application of a Magnus Effect Flow Meter as a Laboratory Teaching Device," *General Motors Engineering Journal*, Vol. 5, No. 4 (October-November-December 1958), p. 12.
2. Cenko, Steve and Harris, Elwood K., "The Development and Use of a Modified V-8 Engine for Student Experimentation," *General Motors Engineering Journal*, Vol. 6, No. 2 (April-May-June 1959), pp. 2-6.

Gaging Roller Bearing Components by Electronic Contour Tracings

By DR. FRANCIS FARAGO
Hyatt Bearings
Division

Dimensional analysis of precision products often requires intricate gaging techniques. Since some products require strict tolerances only on functional surfaces, the wider tolerance limits on non-functional surfaces can pose problems in gaging, such as making it difficult to properly seat or locate the piece for gaging. One product which requires precise dimensions is the roller bearing. At Hyatt Bearings Division, the gaging or analysis of critical surface dimensions of roller bearing components has been made using high magnification, electronic contour tracings. This method provides valuable information on the geometry of critical surface elements. However, the exceptional sensitivity of this method required the development of new locating fixtures and special techniques for interpreting the results.

Special locating fixtures and procedures enable precision analysis

PRODUCTION costs start to rise rapidly when dimensional tolerances are substantially more severe than the level of accuracy common to standard manufacturing methods and equipment. Beyond a certain point the rise in cost usually may be represented as an exponential curve when expressed as a function of the tightened tolerance range. However, exceptions to this empirical rule are often made. These usually occur in an effort to meet the conflicting requirements of continuous improvement in product quality while maintaining competitive prices.

Such requirements call for a thorough evaluation of major product parameters in two areas:

(a) where would the tightening of tolerances result in improved product performance?

(b) where could wider dimensional ranges be allowed without impairing the functional properties?

This functional dimensioning, or loosening the tolerances of non-essential dimensions while severely tightening the tolerances of critical parameters, frequently causes complex gaging problems. Such problems arise particularly when the natural locating surfaces or reference dimensions of a functionally critical section have substantially wider tolerances than those specified for the functional dimensions proper. The provision of non-functional auxiliary surfaces which are needed for location of the part in manufacturing and gaging hardly can be applied in a highly competitive precision product.

The gaging problem becomes harder to solve when it is necessary to measure isolated geometric parameters and, at the same time, to explore the functional interrelations of a critical area.

Roller bearings are typical products where gaging tasks of this nature arise frequently. In antifriction bearings various non-functional surfaces of the component parts have no contact at all. Others are assembly contact surfaces which require tolerances no closer than those usually found on the mating parts, such as shafts and housing bores, in the application of the bearing. On the other hand, the functional surface sections of a modern antifriction bearing must be manufactured with an accuracy which is frequently ten times better than the tolerances allowed for assembly purposes. It is obvious that these accuracy requirements must be thoroughly evaluated when designing the proper gaging.

At Hyatt Bearings Division, methods and equipment have been developed for studying and solving the kind of gaging problems mentioned above. Although this paper presents examples of applications to roller bearings, it is believed that the basic principles of the technique also apply to related fields of high precision manufacturing.

The Gaging Principle: Electronically Magnified Contour Tracings

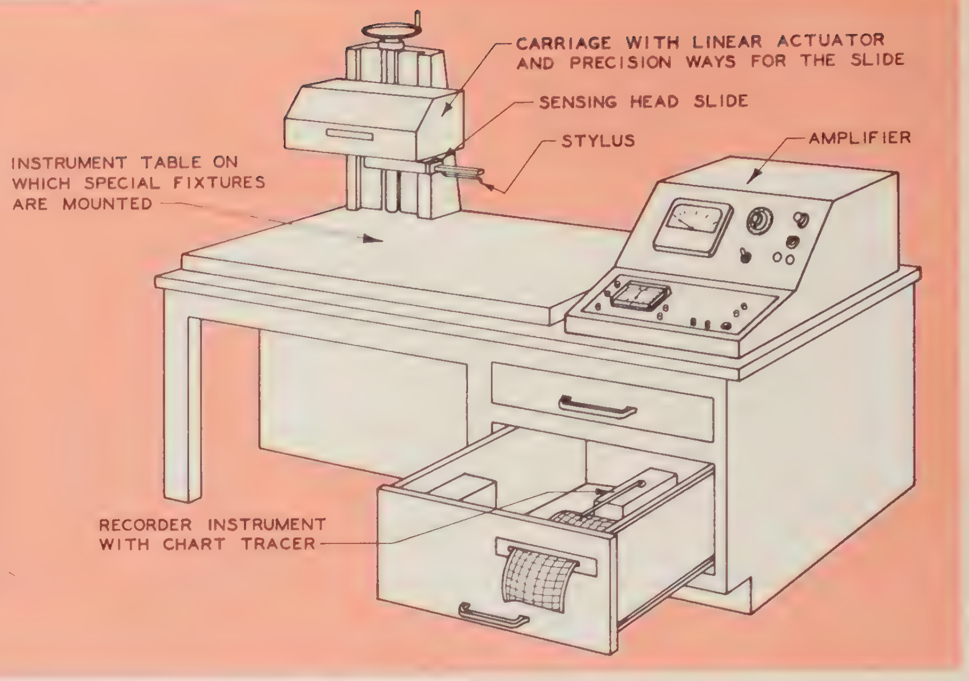
Critical dimensions calling for gaging sensitivity expressed in 10 millionths of an inch are becoming more frequent in the production of fine mechanical components. Linear dimensions, particularly the diameters of cylinders and bores, are now measured to this accuracy by various types of mechanical, air, and electronic gages. However, methods and equipment designed for the measurement of plain linear dimensions are inadequate when characteristics of surfaces such as geometric form, location, and angular position must be gaged in relation to other surface elements. The linear gaging methods are even less adequate when the combined effect of these parameters on the functional adequacy of the surface is under investigation.

When the surface is a surface of revolution, an appropriate way to gage these combined characteristics is provided by an analysis of specific surface elements. When an element is selected in the axial plane of a body of rotation, it will be a section of the contour of that body. Although contour analyses usually are made by means of optical contour projection, this method is not suitable for high precision gaging problems. Two reasons why the optical projection of the contour is unsuitable are:

(a) The maximum magnification in optical projection currently is about 100 times, whereas analyses involving 1/100,000-in. sensitivity require magnifications up to 10,000 times

(b) The optical projection provides a uniform magnification in all directions. This is not appropriate for gaging relatively long contours where the aim is to detect minute variations at right angles to the nominal contour line. If a uniform scale of magnification were used, long contours would require screen dimensions which are impractical. Even in that case, the power of resolution to detect very small, critical deviations from the nominal contour would be inadequate.

Fig. 1—The drawing at the right illustrates the principal components of the electronic contour tracing instrument used for dimensional analysis of roller bearings. Special fixtures (not shown) are used to locate and hold a specimen for gaging. The linear actuator moves the sensing head slide along a horizontal path. The slide advance is synchronized with the chart paper speed in a variable ratio to provide the desired rate of horizontal magnification. The stylus at the extremity of the slide arm follows the contour of the specimen. The stylus moves in a vertical direction to compensate for variations between the theoretical straight path and the actual contour. The stylus motions produce electrical signals which are amplified electronically. The amplified signals are visible on the indicator dial; they also actuate the scriber of the recorder instrument. Roller bearing gagings were made with a non-uniform magnification having a vertical to horizontal magnification ratio of 20 to 1, although many other combinations can be selected.



The electronic contour tracing instruments, now available in several domestic and foreign makes, are capable of satisfying the requirements of exceedingly high magnification and providing different degrees of magnification in the vertical and horizontal directions (Fig. 1). The basic electronic tracer instrument, however, is only one part of a required gaging setup. The stylus of the instrument travels along a fixed path for a specific distance, thus describing a line in space. The specimen must be located and positively held in known relationship to the stylus path to see how this instrument datum line compares with the actual contour of the specimen at a specific section of the contour. The problem of high precision gaging in this case is to positively locate a specimen having complex shaped parts to assure an accuracy commensurate with the 1/100,000-in. gaging sensitivity of the electronic tracer instrument.

Applying the Method to Tapered Rollers

The tapered bearing roller has only two surfaces of functional importance (Fig. 2). These are the conical side and the spherical end face. In advanced designs the side usually has a slight curvature along the straight line element of the cone to provide a crowned contact with the bearing races. These two surfaces must be ground accurately to provide proper function, which involves both the shape and location of the surfaces relative to each other.

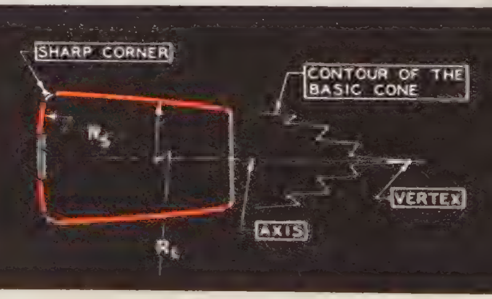
Extensions of the surfaces can be visualized to establish the *sharp corner* intersection of side and end face, the vertex and the axis of the conical side. These elements are not present on the physical component although they are a fundamental part of the design concept which must be considered in gaging. The objective of the gaging operation of the roller side is to measure the several roller parameters (Fig. 3).

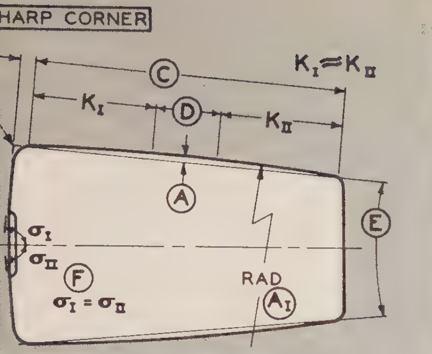
Three-Dimensional Analysis

The geometric conditions which must be established for accurately locating the contour tracing can best be visualized by placing the specimen in an imaginary system of three-dimensional rectilinear coordinates (Fig. 4). In this system the roller surface element to be traced is brought into coincidence with the line of intersection of reference Planes I and II (Fig. 4). Plane III establishes the axial boundary of the space coordinate system and determines the fixed point where all three reference planes intersect. When correctly located, the sharp corner of the roller specimen will coincide with this intersection. The axis of the roller lies in Plane II. Relative to Plane I the roller axis is inclined at an angle $\beta/2$, which is equivalent to half of the included roller angle (a basic design concept). Because the roller end face is a sphere zone whose center of gravity is on the roller axis, it follows that the plate which provides the basis for locating the roller end face must be inclined at the same $\beta/2$ angle in relation to Plane III.

The fact that the roller side element may not necessarily be a straight line contour does not affect the basic concept of specimen location which this geometric analysis visualizes. The straight line element in this analysis is regarded as the line of register of the gaging process which stands for the basic design line of the roller side. The basic design line is a

Fig. 2—The tapered roller is geometrically comparable to a cone frustrum. The sphere radius R_s has a length approximately equal to the distance to the cone vertex. The crown radius R_c has a length of several hundred inches. The words enclosed in a box, *sharp corner, axis, vertex*, and *contour of the basic cone*, denote the basic design elements which are not present on the physical part. The heavy lines indicate functional sections of the contour, which are ground precisely on the finished part.





BEARING ROLLER BY MEANS OF CONTOUR TRACING

SERIAL NUMBER	DIMENSION	GAGING SENSITIVITY
A	CROWN HEIGHT. The chordal height related to a specific gaging distance	0.000010 IN.
A_1	CROWN RADIUS. A derived value, calculated from data	5 IN.
B	LENGTH OF CORNER RADIUS. Distance from the "sharp corner" to the juncture of the radius and roller side	0.001 IN.
C	EFFECTIVE LENGTH OF THE ROLLER SIDE. Distance between the junctures with the corner radii at opposite ends of the roller	0.001 IN.
D	SYMMETRICAL LOCATION OF THE ROLLER CROWN. Location of the peak section of the crowned contour at equal distance K_I, K_{II} from the two end junctures	0.004 IN.
E	Optional Measurements: INCLUDED ANGLE OF THE ROLLER SIDES. The expected gaging sensitivity is based on a roller having about 0.600 in. effective length	0°0'30"
F	END SQUARE. The coincidence of the axis of the roller, as the median of the roller sides, with the axis of a symmetry of the roller end sphere	0°0'30"

Fig. 3—The sketch shown above and the table at the right show the roller parameters which are measured in the gaging process. The desired gaging sensitivity for each parameter is expressed as the smallest increment of dimensional deviation which should be detected and measured in the process.

straight line passing through the sharp corners. This line is in common vertical plane with the roller axis, but is inclined to it so as to include a $\beta/2$ angle with the axis of the roller. The zero position of the indicator stylus during its tracing stroke must coincide with this line of register.

A Fixture to Locate and Hold the Roller

To apply the contour tracing method properly to bearing analysis, special fixtures for locating and holding a specimen were developed at Hyatt Bearings Division. Summarized below are the requirements, and how they were met, in the case of the fixture for bearing rollers (Fig. 5).

- *Requirement:* Hold the specimen during the tracing without interfering with the free movement of the stylus at any position of its travel.
  Method: The fixture holds the specimen by means of a magnet which contacts only the end face surface leaving the whole side surface free.
- *Requirement:* Maintain the roller axis (a design element) in a central plane (Plane II) which will be the plane of stylus point travel.
  Method: The position of the fixture axis is located in this plane by means of members in the instrument table.
- *Requirement:* Present the roller side surface element so that the theoretical side contour—the line of register—coincides with the intersection of Planes I and II.
  Method: The end plate of the fixture which locates the roller end face is part of a sine angle. This can easily be brought into the desired position of incline (at $\beta/2$ angle from the vertical) by means of gage blocks.
- *Requirement:* Establish the location of the sharp corner of the roller on the resulting tracing chart.
  Method: The holding member of the fixture, the carrier, has a tracing stop surface at a specific distance from the spherical end of the roller specimen when this latter is held in the carrier.
- *Requirement:* Provide for the gaging of any number of side surface elements of the roller specimen in the same basic setup.
  Method: Once the roller specimen has been correctly placed on the carrier, the carrier can be rotated in its bushing consistently maintaining the same location for the uppermost side surface element of the roller.

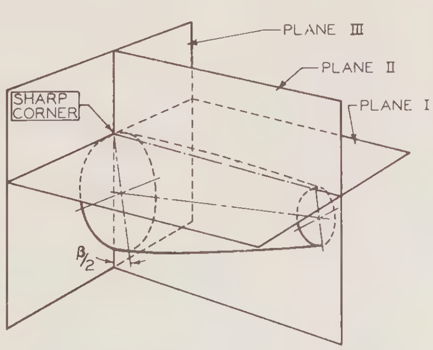


Fig. 4—An imaginary system of three-dimensional rectilinear coordinates is used to visualize the geometric conditions which must be established for accurately locating the specimen part for the contour tracing.

- *Requirement:* Reduce the gaging time by means of a simplified loading of the specimen which assures location commensurate with the required gaging accuracy.
  Method: A special loading device is used which accurately centers the roller in relation to its sides. This device transfers the part to the carrier without interfering with the centered location.

Analyzing Roller Data

A typical contour tracing made from a crowned tapered roller bearing (Fig. 6) reveals a tracing line that has three sections distinctly different in their characteristics:

- A central section which is a slowly rising and falling curve that represents the ground side of the roller

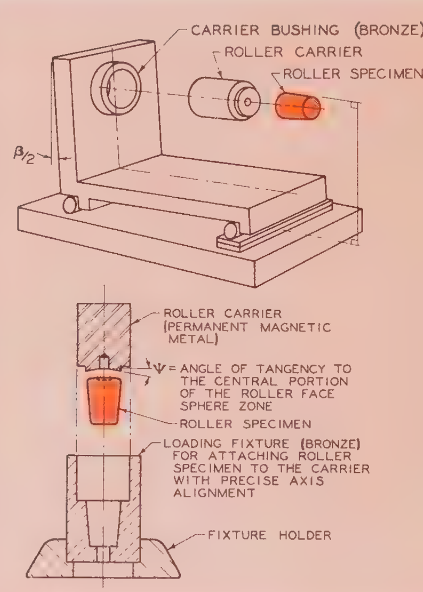


Fig. 5—This work holder, or locating fixture, is placed on the instrument table (upper view). It assures the precise location of a tapered roller for gaging the roller contour. The roller specimen is placed in a loading fixture, which centers the roller in relation to its sides (lower view). The carrier is slipped into the loading fixture and magnetically picks up the roller. The carrier, with the roller attached, is inserted into the bushing of the sine angle fixture. In this position, the roller surface can be traversed by the stylus.

- Two abruptly rising and falling sections, at both ends of the central section, which represent the corner radii of the roller.

The central section of the chart tracing line follows a general direction which is substantially parallel to the line of regis-

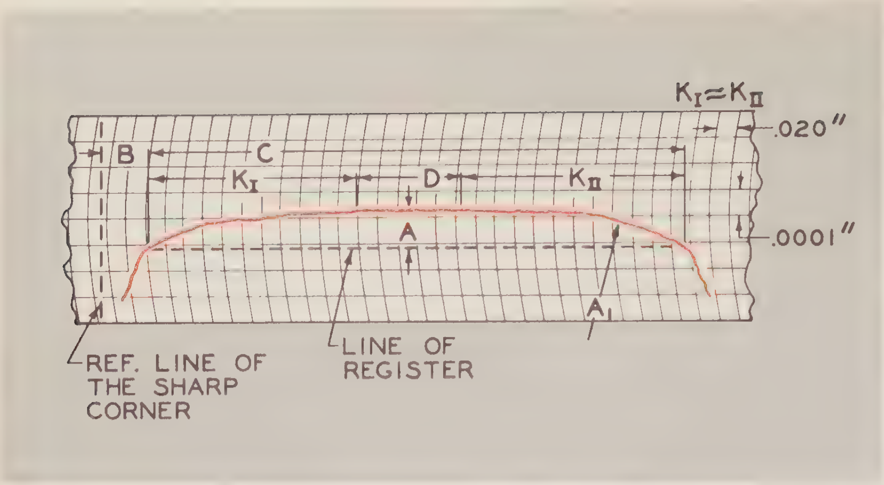


Fig. 6—The reduced scale copy above shows a typical contour tracing made from a crowned tapered roller. The horizontal dashed line represents the line of register. The vertical dashed line is the projection of the *sharp corner* of the roller in a direction perpendicular to the line of register. The magnification in either direction for this tracing is shown at the top of the chart by indicating the actual distance which each division of the chart paper represents. *A* is the dimension between the peak of the central section of the curve and the line of register, or the height of the crown. A_1 is the radius of that curve, when assumed to be a circular arc, calculated from the two known values, namely the chord and chordal height. *B* is the length dimension of the roller corner radius. *C* is the length of the ground section of the roller side surface. This is the functional portion of the roller side. *D* is the location of the central section of the roller contour line, or the zone of the peak. The distance of this section from each of the two junctures (K_I, K_{II}) reveals whether the peak section is in the middle of the roller length.

ter. Consequently, this latter can be used to determine the side length of the roller.

The dimensions of the included angle of the roller sides and the amount of run-out between sides and end face are not marked on the chart (Fig. 6). The measurement of these dimensions by means of the contour tracing method is optional. If the inspection of these dimensions by means of contour tracing is planned, then a total of two or four tracings, all in the same set-up of the specimen, must be prepared. These multiple tracings must represent elements of the roller surface which are located at 180° or at 90° in relation to each other. To prepare such additional tracings, the carrier of the fixture must be rotated into the respective indexing positions without removing the specimen from the carrier.

Applying the Method to the Bearing Inner Race

The rib face of a tapered bearing inner race is another critical functional surface

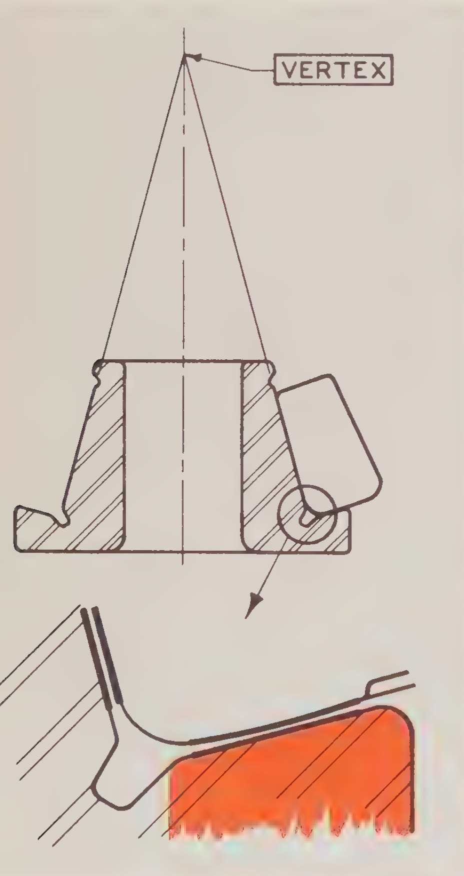


Fig. 7—This cross-sectional drawing of the tapered roller bearing inner race and the enlarged view of the rib face area (in color) show the relationship between the functional surfaces (heavy lines) of the bearing roller and race.

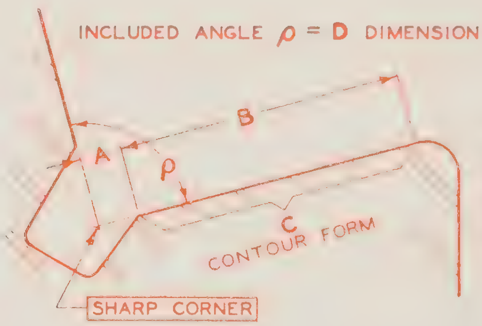


Fig. 8—The sketch at the left shows the critical dimensions of the rib face area. The controlling parameters and the desired degree of gaging sensitivity are listed in the table below.

LIST OF DIMENSIONS MEASURED IN THE RIB FACE AREA OF THE TAPERED ROLLER BEARING INNER RACE		
SERIAL NUMBER	DIMENSION	GAGING SENSITIVITY
A	WIDTH OF THE GRINDING RELIEF. The distance between the "sharp corner" and the juncture of the grinding relief with the actual rib face surface	0.001 IN.
B	EFFECTIVE WIDTH OF THE RIB FACE. The distance radially on the rib face surface between the junctures with the grinding relief and the corner radius respectively	0.001 IN.
C	CONTOUR FORM OF THE RIB FACE. The shape of a radial element, wehther a straight line or curved, and in which direction. Sensitivity required to measure the chordal height of the curvature	0.000010 IN.
D	INCLUDED ANGLE BETWEEN PATHWAY LINE AND RIB FACE (Measured by use of complementary angles). Directly gaging the inclination of the actual rib face contour to a datum line which is at right angles to the pathway line	0°0'30"

requiring great accuracy in form and location. It is the surface which contacts the spherical end face of the roller, and it determines the axial location of these bearing elements (Fig. 7). The desired accuracies require a ground surface carefully located with respect to the conical elements of the basic bearing geometry. Contour tracing is applicable to gaging because a single measurement determines the contour form and its position relative to other critical parameters (Fig. 8).

Although the nominal surface elements usually are used as zero reading reference lines for the tracings, a deviation from this principle is preferable for gaging the inner race rib face angle. The reason is that the included angle (Fig. 8) is, with very few exceptions, always greater than 89° and less than 90°. It is more practical to locate the specimen in a position where the stylus zero indication will coincide with an angle at 90° to the conical pathway element. Since the stylus point travels primarily in a horizontal direction, the position can be accomplished by bringing the conical element into a vertical position.

The sharp corner (Fig. 8) is again a design concept used as a reference point for dimensioning and gaging. It is the projected intersection of the pathway and rib face elements. This sharp corner of the specimen must be brought into coincidence with the point of intersection of the three rectilinear planes (Fig. 9). At the same time, the zero indication path of the stylus must coincide with the intersection of Planes I and II and the conical pathway element must coincide with the intersection of Planes II and III.

The axis of the bearing race specimen must be tilted to have the selected element of the pathway contained in the vertical plane. The tilt angle is one half of the inner race body angle, which is the angle included between the diametrically opposite elements of the race pathway.

There were several requirements to be satisfied in developing a proper locating and holding fixture for the bearing inner race (Fig. 10). These requirements, and the methods of meeting them, are as follows.

- *Requirement:* The work holding device must be centered with respect to the path of the tracer stylus.
  Method: The line connecting the axes of the two centers is located at a specific distance from a reference surface on the side of the fixture base. The pivot axis of the sine angle on which these centers are held is perpendicular to the same reference surface. Consequently, a tilting of the sine angle does not interfere with the location of the vertical reference plane which contains the center axes.

- *Requirement:* The axis of the specimen inner race must be contained in the same vertical reference plane which contains the path of the stylus to assure that the stylus will trace a radial element on the surface of the specimen.
  Method: The part is held in the fixture by means of a mandrel fitting into the inner race bore, which has a close tolerance. The mandrel, having precisely ground center holes, is clamped through these holes between the centers of the fixture.

- *Requirement:* The pathway element of the inner race specimen closest to the tracer unit must be contained in reference Plane II and located in a vertical position perpendicular to the path of stylus travel.
  Method: The angular position of the opposite side elements of the race pathway is assumed to be symmetrical with respect to the inner race axis at an included angle of known magnitude. The sine angle of the fixture is adjusted to be exactly one half of this included body angle.

- *Requirement:* The sharp corner of the inner race side element and radial flange face element must have a positive location with respect to the starting point of the tracing time.
  Method: The sharp corner lies on the extension of the vertically located pathway element. Consequently, when the contact point of the tracer head, which is moving in a horizontal plane, has been advanced to establish contact with the pathway element, the position of this contact will be just above the sharp corner. For this purpose the tracer head is equipped with an end stop which is at a known distance from the point of the stylus, when viewed in a horizontal plane projection (Fig. 11). This distance then can be transferred to the tracing chart to establish the datum line of the pathway elements.

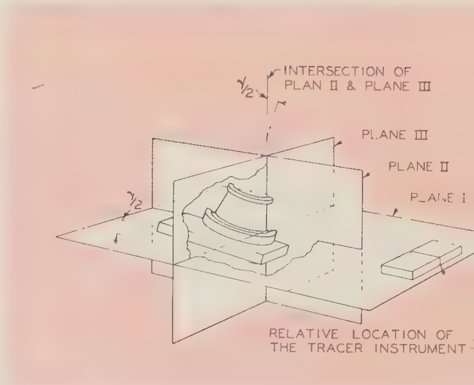
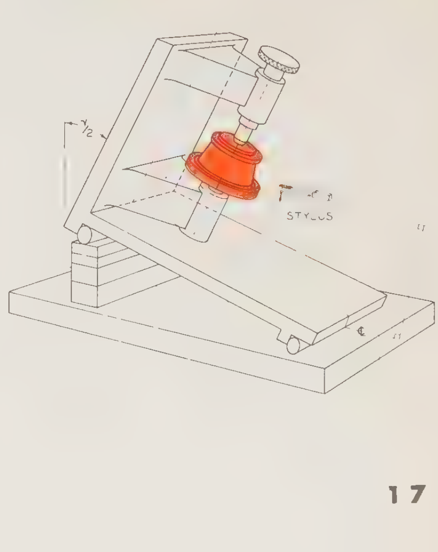


Fig. 9—Three reference planes are used to visualize the location of the bearing inner race specimen for contour tracing. Plane I is parallel to the base plate surface of the gage. It is the horizontal plane on which the stylus point would have a zero indication. Plane II contains the axis of the race specimen. The path of the stylus is confined to this plane. Plane III contains the pathway element located closest to the trace instrument. The common point of intersection of all three planes coincides with the sharp corner of the inner race. The axis of the bearing race specimen must be tilted by the angle $\gamma/2$ to have the selected element of the pathway contained in the vertical plane. The angle $\gamma/2$ is one half the inner race body angle, which is the angle included between the diametrically opposite elements of the race pathway.

Proper Interpretation of Tracings Enables Study of Roller-Race Contact

In addition to the contour tracing line, the entire chart that is produced by the tracing machine must be provided with markings which aid interpretation of bearing information (Fig. 12). With the exception of the location of the pathway line, these markings are derived from the tracing. The pathway line is the ordinate of the chart, located at a specific horizontal distance from the starting point

Fig. 10—Shown below is the special work holder, or locating fixture, developed to locate the bearing inner race specimen for tracing. The inner race is held on an arbor inserted between the points of two centers attached to the sine angle fixture.



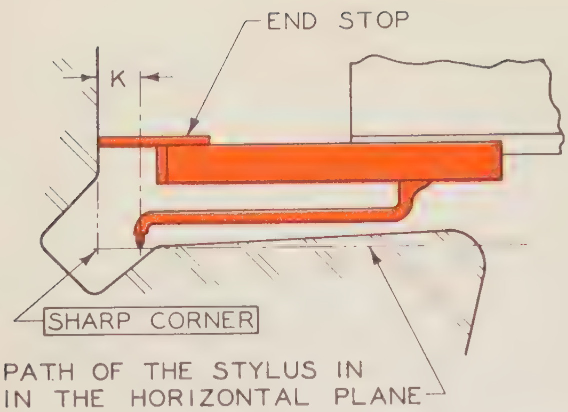


Fig. 11—An end position stop for the tracer head assures a fixed distance K between the vertical reference surface (Plane III) and the stylus point at its starting position.

of the tracing line. The actual value of this distance is established by the amount of overhang to which the end stop is adjusted with respect to the stylus point (Fig. 11). This physical dimension then must be transferred to the chart in the scale of the applied horizontal magnification. The scale markings are established by dividing the actual chart graduations by the rates of vertical and horizontal magnification selected for the particular tracing.

In compliance with the specified sensitivity requirements (Fig. 8), critical design dimensions of the race specimen can be determined from the tracing (Fig. 12), as follows:

(a) The included angle ρ between pathway and rib face. This angle is calculated from the chart dimensions of the rectangular triangle. The hypotenuse of the triangle is the length of the substantially straight portion of the tracing line. The side of the triangle is equivalent to the rise from the horizontal which passes through the starting point of the straight portion of the tracing line. This imaginary triangle permits the calculation of the value of an angle σ which represents the deviation of the actual rib face contour line from the horizontal reference line to which the pathway line is perpendicular. According to the chart, $H = 0.00060$ in., $B = 0.040$ in., $H/B = \tan \sigma$. Therefore,

$$\frac{0.00060}{0.040} = 0.015$$

$$0.015 = \tan 0^\circ\ 51'\ 34''$$

To determine the included angle ρ,

$$\rho = 90^\circ - \tan \sigma$$
$$\rho = 90^\circ - 0^\circ\ 51'\ 34''$$
$$\rho = 89^\circ\ 8'\ 26''$$

(b) The width of the grinding relief A (when K is adjusted to equal 0.034 in.):

0.034 in. + 0.004 in. = 0.038 in.

(c) The effective width of the rib face (ten horizontal divisions on the chart): 0.040 in.

(d) The general characteristic of the rib face contour, which in the selected example is a substantially straight line with a convexity less than 0.00005 in. high.

When the contour of the rib face is a substantially straight line, the included angle between the pathway and the rib face can be calculated by means of a properly prepared rib face tracing. Since the radius of the mating roller end face sphere is a controlled dimension, it also is possible to establish geometrically that point where the roller end of known radius will first contact the known rib face contour line. However, the geometric conditions become much more complex when the rib face contour is a curved line, either concave or convex. In such cases it usually is not practical to predict the position of the contact area between roller and rib face by means of a geometric analysis.

To handle these complex conditions a special method has been developed for functional evaluation of the rib face form using a contour tracing. Essentially, this method consists of the following:

(a) Simulating the portion of the nominal roller end face which contacts the rib face in the assembled bearing

(b) Applying this roller contour to the rib face contour chart in the position which closely simulates the actual conditions in the bearing assembly

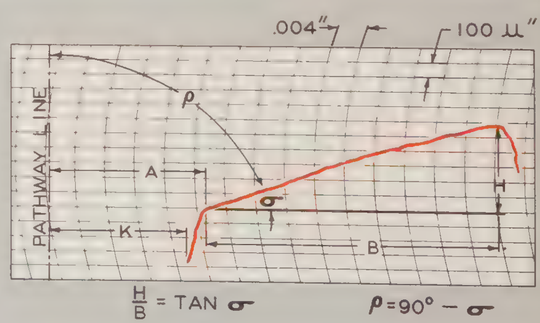
(c) Bringing the roller contour into contact with the rib face contour line to produce the following conditions:

- Where the first contact occurs (initial point of contact)
- Where the distance between the intersections of these two contour lines becomes equivalent to an assumed wear track width of the roller on the rib face. (This wear track width is an empirical dimension usually considered constant for any given type of bearing operating under specific load conditions.)

The preceding steps in the process of functional evaluation can be accomplished by the following methods:

(a) First, the contour of the roller section must be simulated. The functional section of the roller end is a sphere zone with known nominal radius. Consequently, its cross sectional contour will be a circular arc having the same radius.

Fig. 12—A typical contour tracing of an inner race specimen shows the following parameters: the width of the grinding relief, the effective rib face width, and ρ, the angle included between the pathway line and the rib face. The critical design dimensions of the specimen can be determined from the tracing in compliance with the specified sensitivity requirements (Fig. 8).



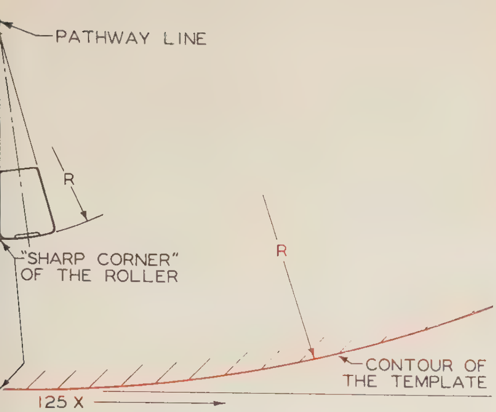


Fig. 13—To aid in analysis, the contour of the spherical end face of a roller can be reproduced in the form of a template. The template contour is based on a non-uniform magnification in the horizontal and vertical direction which is identical to that used for the contour tracing. The cross section of the tapered roller shows the relationship of the locating positions where the pathway line coincides with the side element of the roller and the origin of the system of coordinates used to construct the template coincides with the sharp corner of the roller.

The roller face which makes contact with the race pathway is, in a sectional view, a section of this circular arc.

If the rib face contour tracing used a uniform scale magnification horizontally and vertically, the roller end contour could be simulated simply by drawing a circle with a radius which is equal to the nominal radius multiplied by the applied rate of uniform magnification.

As explained above, the objectives of the contour tracing can only be accomplished when a non-uniform magnification is applied. Consequently, if the contour of the mating element—the roller end—is applied to the rib face contour tracing, the contour of the roller end must be designed

ig. 14—The contour tracing shown below illustrates e application of a template to simulate expected erating conditions. The width of the wear track *W* oduced by the roller face on the rib face is shown.

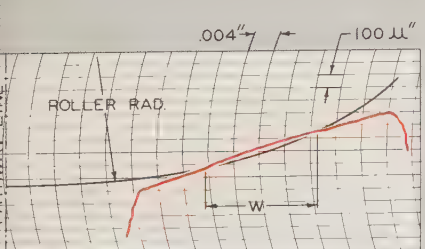


Fig 15—The device shown in the schematic drawing at the right was designed to facilitate the approach movement of the roller end face contour template in relation to the rib face contour tracing. The device consists of a frame *A* and slide *B*, template holder pins *C* and the template *D*, a guideway for the slide *E*, and chart holder clamps *F*. The strip chart with tracing *G* is located so the vertical reference line *H* is in register. By using this device, a strip chart *J* with tracing and wear track produced by the roller end control is made.

in the same non-uniform magnifications used in preparing the tracing.

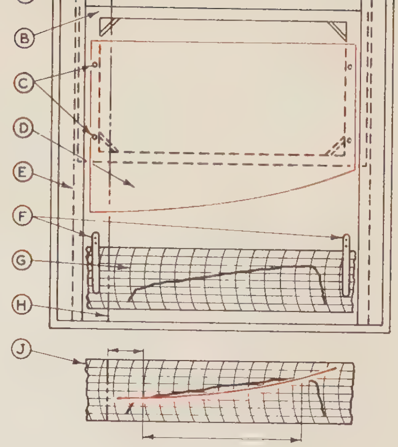
One method for constructing a circular arc in the scale of the tracing is to calculate the numerical coordinate values of closely placed points of the circular arc. These points can be plotted on the contour tracing and connected by a continuous curve. For repetitive use, a template can be made whose physical contour coincides with this simulated curve (Fig. 13).

(b) To apply the simulated contour line of the roller end with correct relationship to the rib face tracing, the reference line of the roller contour, which represents the roller side, must coincide with the vertical reference line of the rib face tracing, which represents the pathway line.

(c) When bringing the roller end contour into contact with the rib face contour line, the positions of the two reference lines, representing the roller side and pathway line, must stay in coincidence.

A typical example of the simulated contact obtained by this method (Fig. 14) shows that the presentation of the conditions simulated to represent the actual bearing permit a thorough analysis of the functional properties of the rib face contour.

A special device has been designed to facilitate the approach movement of the roller end contour template in relation to the rib face contour tracing. This device rigorously maintains the coincidence of the two vertical reference lines (Fig. 15). It consists essentially of a slide holding the roller end contour template, which can be moved in guides integral with a base board. The rib face contour chart is clamped to the board. When the template reaches the appropriate position in relation to the rib face contour line, the template may be used as a ruler and a line drawn across the rib face contour line. The relationship of these lines represents the predicted roller end position with respect to the bearing race rib



face. This device provides a rapid method of preparing a permanent record of the expected operating conditions, which can be used for a thorough functional analysis of this critical area of the tapered roller bearing.

Summary

High magnification contour tracings, when properly prepared, provide valuable information on the geometry of critical surface elements. However, the exceptional sensitivity of electronic gaging requires special procedures to realize the objectives by gaging the functional design characteristics of the specimen. New concepts of locating the work piece for the gaging must be applied and special techniques have to be used for the interpretation of the resulting tracings.

Bibliography

The following literature is related to the subject matter discussed in this paper, although not as direct source material.

ALLAN, R. K., *Rolling Bearings* (London, England: Pitman Ltd.) 1945.

BUCKINGHAM, E., *Dimensions and Tolerances* (New York: The Industrial Press) 1954.

KENNEDY, C. W., *Inspection and Gaging* (New York: The Industrial Press) 1954.

LEINWEBER, P., *Taschenbuch de Langenmesstechnik* (Handbook of Metrology), Berlin, Springer Verlag, 1954.

LURJE, G. B., *Technology of Anti-Friction Bearing Manufacture* (Translation into Hungarian, revised by F. Farago) Budapest, Nehezipari Kiado, 1951.

RANTSCH, K., *Grundlagen der Techn. Winkelmessungen* (*Techn. Angle Gaging Fundamentals*) Berlin, Springer Verlag, 1952.

SIMON, P., and FARAGO, F., *Handbook of Toolmaking* (Sections on Gaging and Fixture Design), Second Edition, Budapest, Nehezipari Kiado, 1954.

A Survey of Some Currently Available Ceramic Materials

By CARL F. SCHAEFER
AC Spark Plug
Division

A ceramic material may be the solution to an engineering problem

The engineer's task of developing a new product or improving an existing one includes making use of new techniques, new devices, or new materials whenever these appear to be appropriate. New materials, for example, can replace traditional ones to achieve various design objectives such as better quality, improved performance, or a more efficient manufacturing process. Ceramic materials are examples of those which can be used successfully to replace certain other materials. Because of the rapid advance of technology in the ceramics industry, an increasing number of ceramic materials now are commercially available for application to design problems. These materials may be classified by two general terms: *dense* and *porous*. To apply them properly, the engineer needs to be familiar with the characteristics of each type as well as the means of fabricating a ceramic part.

THE demand for materials to meet new and unusual requirements, generated by the rapid increase in the rate of technological progress, is certainly well known. Less publicized, but no less important, is the fact that many materials which were mere laboratory curiosities only a few years ago are now commercially available and at a reasonable cost.

The products of the ceramic industry are no exception. Within recent years, several new members have been added to the family of ceramics and, at the same time, refinements in manufacturing have extended the usefulness of the more venerable members. In view of this condition, a review of some of the currently available ceramic products which, conceivably, could be used to replace less satisfactory, traditional materials may be profitable.

When properly used, ceramics—with their inherent stability—offer opportunities for ruggedness, durability, and compactness of construction which are sometimes difficult to achieve with plastic or metal components. Ceramics having compression strengths in excess of 300,000 psi are not uncommon, although hardness may vary from one extreme to the other. Materials are available which have thermal expansions in the range of metals, while others are made which actually have zero or negative expansion. At least one ceramic is available with thermal conductivity as high as that of aluminum, while others are excellent thermal insulators. Most are good electrical insulators but some possess useful semiconducting properties.

Dense Ceramics Feature Superior Mechanical and Electrical Properties

One prominent group of ceramic materials is composed of *dense*, fine-grained materials (Table I).

Alumina Type Bodies

Of these dense materials, the alumina ceramics—those in which aluminum oxide Al_2O_3 comprises the primary crystalline phase—are undoubtedly the center of current interest. Ceramics in this category are characterized by high compression strength, extreme hardness, moderately high thermal conductivity, and refractoriness. Generally speaking, they are excellent electrical insulators.

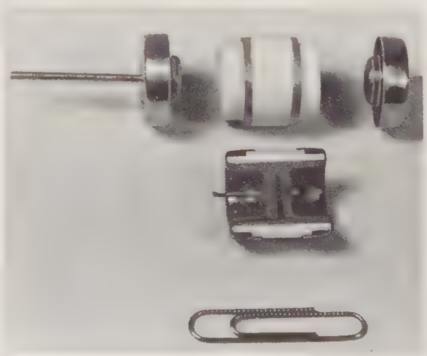


Fig. 1—An example of a ceramic-to-metal seal is this electronic tube assembly, showing a metallized alumina ceramic envelope soldered to metal end covers.

The properties of these bodies vary in proportion to the amount of Al_2O_3 present, as well as to the amount of residual porosity. Commercial compositions range from approximately 85 per cent Al_2O_3 to essentially 100 per cent Al_2O_3, and absorption varies from about 15 per cent to essentially zero.

Like virtually all materials, ceramics undergo a deterioration in properties with increasing temperature. For ceramics, electrical conductivity, dielectric constant, and electrical loss factor increase, while strength and thermal conductivity decrease. Although not evident from the data shown in Table I, since the values given are for room temperature, the alumina ceramic material possesses a significant advantage over the other materials in the retention of its desirable properties at elevated temperatures. This fact alone accounts for its use as an electrical insulator in many applications where heat and high frequencies are involved.

In addition, many applications, such as in gages and machine parts, stem primarily from alumina's combination of high strength and hardness. Alumina is of the same order of hardness as cemented carbides, yet it is much lighter in weight and is generally stronger. Using diamond grinding techniques, it can be machined to close tolerances with excellent surface finish. At the same time, it is highly resistant to heat or chemically induced corrosion, and to galling under load. Seal rings and pump parts for the handling of corrosive or abrasive liquids are examples of such applications, as well as precision bearings and gyroscope parts. Cutting tools are another use based primarily on the combination of hardness and strength.

Due to its high strength, alumina also is used increasingly as a component where ceramic-to-metal seals are required (Fig. 1). Metals are available which closely match alumina in thermal expansion but, at the same time, other ductile metals can be satisfactorily sealed to it, merely because it is strong enough to withstand the stress imposed by mismatch. Of course, proper design is essential in such cases. The use of alumina tube envelopes as a replacement for glass has resulted in a large increase in ruggedness and performance in electronic equipment.

Currently being manufactured are such diverse items as radomes, grinding and heat exchange media, molds for metal casting, sand blast nozzles and thread guides, to name only a few.

Other Single-Oxide Bodies

Prior to the advent of alumina bodies, most of the fine-grained ceramics were of the so called porcelain type bodies; that is, they comprised mixtures of clay with silica and feldspar, or other naturally occurring, mineral materials. The commercial development of alumina ware demonstrated the feasibility of producing ceramic products of pre-refined, nearly pure materials, and a variety of these are now available on the commercial market. It is doubtful that any one material possesses the combination of desirable properties that alumina does, yet several may surpass it with respect to some particular property.

For instance, beryllium oxide bodies have assumed an important place in the list of materials used for nuclear energy applications. Aside from this, beryllia possesses at least one property which is of prime interest, namely, its very high thermal conductivity. At room temperature, the conductivity of sintered beryllia is of the same order as that of aluminum metal, making it unique among ceramic materials. It also is moderately strong, an excellent electrical insulator, and it has good chemical stability. Due largely to its high thermal conductivity, sintered beryllia has very good resistance to thermal shock.

Compared to most ceramic materials, beryllia is expensive. The raw material is costly and it is toxic when in a finely divided state. Hence, extraordinary precautions are required during processing, which adds appreciably to the price of the product. It should be noted that beryllium oxide ceramics are not toxic

PHYSICAL PROPERTIES OF SOME DENSE, FINE-GRAINED CERAMIC MATERIALS

PROPERTY	UNITS	95 TO 100 PER CENT ALUMINA	85 PER CENT ALUMINA	BERYLLIA	ZIRCON PORCELAIN	LITHIUM-ALUMINO-SILICATE	MAGNESIA	PYROCERAM**	FELDSPATHIC PORCELAIN	STEATITE	FORSTERITE	TITANIA	CORDIERITE
MODULUS OF RUPTURE	PSI X 1,000	45 TO 60	35 TO 45	32 TO 36	13 TO 26	8	20	16 TO 23	9 TO 12	18 TO 20	20	20	15
COMPRESSIVE STRENGTH	PSI X 1,000	300	200 TO 300	225	60 TO 100	60	90	--	40 TO 90	75 TO 90	85	100	50 TO 95
TENSILE STRENGTH	PSI X 1,000	25 TO 35	28 TO 32	--	7 TO 12	--	--	--	3.3 TO 4.5	7.5 TO 10	10	7.5	--
IMPACT RESISTANCE	IN-LB	7 TO 8	6 TO 7	--	5 TO 5.5	--	--	--	2.6 TO 4.8	4.3 TO 5.0	4	6.5	4.0 TO 4.4
MODULUS OF ELASTICITY	PSI X 1,000	40 TO 50	28 TO 32	46	--	--	36	12.5 TO 17.3	10 TO 15	--	--	--	--
HARDNESS	MHO SCALE	9	9 TO 9	--	8	--	--	--	6 TO 8.5	7.5 TO 8.0	7.5	8	7.5 TO 8
SPECIFIC GRAVITY (BULK)	G PER IN.^{2}	3.7 TO 3.9	3.4 TO 3.5	2.85 TO 2.9	3.0 TO 3.7	--	3.3 TO 3.4	2.5 TO 2.6	2.35 TO 2.53	2.5 TO 2.8	2.8 TO 3.0	4.0	2.3 TO 2.65
DIELECTRIC STRENGTH	V PER MM	200 TO 250	200 TO 250	240 TO 250	210 TO 250	--	150	--	240 TO 270	210 TO 250	240	100	225
DIELECTRIC CONSTANT	--	9.0 TO 9.6	8.1 TO 8.7	6.5 TO 6.6	7.0 TO 8.8	--	8.9	5.6 TO 6.9	5.7 TO 6.1	5.6 TO 6.3	6.2 TO 6.3	85	5.3 TO 6.2
POWER FACTOR	--	0.0003 TO 0.0009	0.0007 TO 0.001	--	0.001 TO 0.008	--	--	0.0015 TO 0.003	0.006 TO 0.012	0.0007 TO 0.0035	0.0014	0.001	0.005 TO 0.009
ELECTRICAL LOSS FACTOR	--	0.002 TO 0.009	0.010 TO 0.014	0.0008 TO 0.0009	0.006 TO 0.012	--	0.0006	0.008 TO 0.02	0.036 TO 0.069	0.004 TO 0.02	0.009	--	0.025 TO 0.06
Te VALUE†	C°	900 TO 1,000	800 TO 850	--	700 TO 800	--	1,160	--	350 TO 650	440 TO 870	1,000	520	485
THERMAL CONDUCTIVITY	CAL PER CM^2 PER CM PER SEC PER C°	0.045 TO 0.055	0.03 TO 0.04	5.9 TO 6.0*	0.003 TO 0.012	0.005	0.08	0.005 TO 0.009	0.004 TO 0.009	0.006 TO 0.008	0.008	0.012	0.008 TO 0.010
THERMAL EXPANSION COEFFICIENT	X 10^6 PER C°	7.0 TO 8.0	6.5 TO 7.5	9.2 TO 9.4	4.5 TO 5.0	1.15	10.1	0.04 TO 5.7	3.8 TO 6.0	7.0 TO 9.0	10.5 TO 11.0	10	3.3 TO 4.1
SPECIFIC HEAT	CAL PER G°C°	0.19	0.18	0.31	--	--	--	--	--	--	--	--	--
MAXIMUM SERVICE TEMPERATURE	C°	1,500 TO 1,700	1,000 TO 1,450	--	1,100 TO 1,300	0.005	--	--	1,000 TO 1,300	1,000	1,000	1,000	1,200

*SECONDS TO REACH A STANDARD THERMAL GRADIENT IN A RIGHT CYLINDER, COMPARED TO 5.1 FOR COPPER, 6.8 FOR BRASS, AND 11.8 FOR ALUMINA CERAMIC

**TRADE NAME

†THE TEMPERATURE AT WHICH THE ELECTRICAL RESISTANCE ACROSS ONE CM^3 IS ONE MEGOHM

Table I—This table, based on a survey of the products of many ceramic suppliers, shows the physical properties of some dense, fine-grained ceramic materials. The data are not intended to be a specific listing, but rather a composite one. In most cases, a range of values is shown which illustrates the extent to which the various properties may differ depending on compositional or processing variations.

in the massive form, and they can be used in most cases with impunity.

Zirconium oxide, titanium dioxide, and magnesium oxide ceramics are also commercially available, and find application where their particular properties make them especially useful. A zirconium oxide material is often used in the form of crucibles for melting metals, because of its refractoriness and resistance to chemical attack. A titanium dioxide material is sometimes used to make thread guides where dissipation of static is a problem, since its electrical properties may readily be adjusted to permit leakage of a static charge to ground. Magnesium oxide, like zirconium oxide, is an extremely refractory material. At the same time, it has good high-voltage resistance at elevated temperatures, and it is a good thermal conductor.

Multi-Oxide Bodies

Other ceramic materials are produced in which the primary crystalline phase is not a single oxide, but rather a mixture of oxides or a compound composed of two or more oxides. Examples of this type of material are steatite, ordinary electrical porcelain, cordierite, zircon, forsterite, and the lithium alumino silicates.

Steatite ceramics are those in which clinoenstatite ($MgO \cdot SiO_2$) predominates. Perhaps the easiest of all ceramic bodies to fabricate, it is used to make an array of insulators for high frequency applications, many of which are intricately shaped. Compared to alumina, its strength is only moderate, it is relatively soft, and it is considerably less refractory. Steatite is manufactured in a wide variety of grades with electrical or physical properties adjusted to suit particular conditions. It is less expensive than alumina, and it is used when premium properties are not required.

The so called electrical porcelain materials are composed of mixtures of clay, silica, and feldspar. Like steatite, they are relatively easy to fabricate, their raw materials are inexpensive and, as a result, they are generally the lowest cost, fine-grained ceramics available. Both electrical and mechanical properties are mediocre, and they find use in only the most unsophisticated applications.

Cordierite ($2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$) and the lithium-alumino-silicate bodies possess one characteristic which is most unusual—extremely low or even negative thermal expansion. Their utility is based on this property. Because of their very low thermal expansion, they possess excellent resistance to thermal shock. Some parts made of this type material can, for instance, withstand repeated quenching in water from red heat without damage. Few other ceramics can match this property. They are not particularly refractory, and their use is limited to a maximum temperature of about 2,400°F. However, they are used to produce such items as heater supports, burner tips, welding jigs or fixtures, immersion type protection tubes, furnace boats, and precision molds. In many cases, they may be used as a substitute for fused quartz or graphite.

Forsterite ($2MgO \cdot SiO_2$) ceramics possess very good electrical properties and they have relatively high thermal expansion—on the order of 11×10^{-6}. For these reasons, they are often used for the fabrication of ceramic-to-metal seals, their expansion being sufficiently close to that of iron to permit a joining of the two. Lead-through insulators (Fig. 2), power tubes, and other electronic components are the most common products.

A relatively recent development is the group of fine-grained, crystalline ceramic materials produced under the trade name *Pyroceram*. These ceramics are unique in that they are fabricated by a method quite different from other bodies. A glass batch containing suitable nucleating agents is melted and formed into a transparent glass article by conventional glass making techniques. The product is cooled to a temperature inducing precipitation of the nucleating agents. Then the nucleated article is reheated to a temperature at which growth of the nucleated crystals takes place. Composition of the glass and the degree of heat treatment determines the type of crystallization and the properties.

Ceramics produced by this means are exceedingly homogeneous. Electrical properties are good with relatively small variation due to temperature change. Strength is only fair compared to alumina; however, thermal shock resistance is excellent due to low thermal expansion.

Porous Ceramics Desired for Some Applications

A second general group of ceramic materials is made up of *porous* materials. Although most ceramic materials are produced to be essentially non-porous, that is, they will not absorb a significant amount of water, porosity is desirable for certain applications. Thus, some ceramics are manufactured with deliberately high porosity (Table II). The mechanical and electrical properties of these porous materials are inferior to comparable dense ceramic materials. However, the degraded properties are accepted to attain the relatively open structure needed for a particular application.

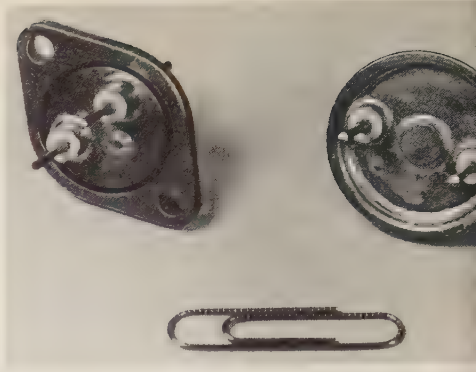


Fig. 2—A typical ceramic-metal lead-through assembly shows metallized ceramic insulators soldered to both the central conductor and the surrounding base plate. A lead-through insulator is used where a conductor must pass through the wall of an enclosure. The ceramic must insulate the conductor from the wall, and often must provide a gas-tight seal.

Porous ceramics often are used as insulators or supports in vacuum tubes. Here it is essential to produce a high vacuum within the tube and, if any of the components do not readily give off internally held gases, the evacuation process becomes difficult. By using support insulators which have a very open structure, the out-gassing, or removal of gas, is facilitated.

Other porous materials are the so-called crushable ceramics. This type of material is used where it is desired to enclose an electrical conductor inside a protective metal sheath with an insulator interposed. Examples are thermocouple probes or electric heating elements. In this type of application, the ceramic generally is fabricated in a tubular form so that it can be inserted inside the metal sheath with a wire or wires extending through the center. The assembly then is swaged, crushing the ceramic into a tightly compacted mass between the wire and outer sheath. The objective is to achieve intimate contact between all of the components to obtain good thermal conductivity while maintaining electrical

insulation between the wire and sheath. For such an operation it is desirable to have a low strength, porous ceramic to provide for easy crushing.

Another important use for porous ceramics relates to metal casting. In this case, the ceramic part serves as an insert or core during casting and is removed before the part is finished. Removal is usually accomplished by solution or disintegration of the insert by molten salts. Porosity is desirable for easy penetration of the solvent.

PHYSICAL PROPERTIES OF SOME POROUS, FINE-GRAINED CERAMIC MATERIALS

PROPERTY	UNITS	100 PER CENT ALUMINA	CORDIERITE	LITHIUM-ALUMINO-SILICATE	ZIRCONIA
MODULUS OF RUPTURE	PSI X 1,000	8 TO 22	6 TO 8	4.2	4
COMPRESSIVE STRENGTH	PSI X 1,000	10 TO 80	30 TO 60	6 TO 20	10
TENSILE STRENGTH	PSI X 1,000	--	2.4 TO 3.5	--	--
IMPACT RESISTANCE	IN-LB	3 TO 4	2.2 TO 2.5	--	4
SPECIFIC GRAVITY (BULK)	G PER CM^3	2.4 TO 2.6	2.0 TO 2.1	--	2.9
DIELECTRIC STRENGTH	V PER MM	50	100	--	--
DIELECTRIC CONSTANT	--	5.5	3.5 TO 5.0	--	--
POWER FACTOR	--	0.0005 TO 0.002	0.004 TO 0.008	--	--
ELECTRICAL LOSS FACTOR	--	0.003 TO 0.014	0.020 TO 0.029	--	--
Te VALUE	C°	800 TO 1,000	240 TO 780	--	610
THERMAL CONDUCTIVITY	CAL PER CM^2 PER CM PER SEC PER C°	0.004	0.003 TO 0.010	0.004	0.004
THERMAL EXPANSION COEFFICIENT	X 10^6 PER C°	6.5 TO 8	2.8 TO 2.9	0.63 TO 0.65	9.6
MAXIMUM SERVICE TEMPERATURE	C°	1,300 TO 1,700	1,250 TO 1,290	1,100 TO 1,300	1,600
WATER ABSORPTION	PER CENT	5 TO 18	2 TO 15	10 TO 22	12 TO 16

Table II—This table, also based on the survey mentioned in Table I, is a composite listing of the physical properties of some porous, fine-grained ceramic materials.

Fabrication Technique Depends on Type of Part and Nature of Material

Besides a knowledge of the physical properties of ceramic materials, the engineer also should know how ceramic structures are fabricated, since these processes may have inherent advantages or disadvantages important to his design. Most fine-grained ceramic products are fabricated using one of four basic processes:

- Pressing
- Extrusion
- Isostatic molding
- Slip casting.

These processes are used to produce the desired shape in combination with various machining operations. Which process should be employed in a given case depends on both the geometry of the part being made and the nature of the material involved.

Pressing

The *pressing* process is exactly what the name implies; ceramic material in a powdered or granular form is placed in a die cavity and compressed between punches (Fig. 3). Such a method is most often used to produce plate-like parts, where the ratio of thickness to area is relatively small (Fig. 4). Pressing is not used where the reverse condition exists because of the resulting lack of uniform density when the distance between compressed surfaces is large.

The pressing method has certain advantages. Parts produced need not be symmetrical and the cross section through the die may be virtually any shape, providing that the part can be ejected once it is pressed. Likewise, the punch surfaces may, within limits, be contoured to provide a surface pattern. Holes through the part may be produced by using core pins, which also may be arranged in a nonsymmetrical pattern.

Extrusion

The *extrusion* process employs the principle of forcing a plastic material through a die to produce a rod-like form that may be cut to any suitable length (Fig. 5). The desired ceramic material is used in a plastic or semiplastic condition. It is placed in a cylinder and forced through a die by a piston. Generally speaking, the cross section of extruded ware should be symmetrical and of reasonably uniform wall thickness. Holes in an axial direction may be produced by the use of core pins in the die.

Isostatic Molding

Pressure applied during forming by pressing or extrusion is directional; therefore, orientation or variable density may occur within the piece. Furthermore, because of the large movement of the materials over the die surfaces as pressure is applied, tool wear is sometimes a considerable problem. The *isostatic molding* process provides a means of at least partially overcoming these objections (Fig. 6). In this process, powdered or granular material is placed in an elastic container. The container is subjected to hydraulic pressure from the outside, uniformly compressing the material contained within. As in the other processes, a core pin may be used to produce a central bore, although the limitations in this respect are considerably more stringent than with either pressing or extrusion. The density within a part molded in this manner is more uniform than that achieved by other means, and tool wear is considerably reduced. However, the method does not produce a finished outer surface, and secondary machining operations are almost invariably required. For this reason, isostatic molding may be more expensive to employ than other methods.

Slip Casting

Slip casting is done by pouring a water slurry of ceramic material into molds made of plaster of Paris (Fig. 7). The amount of water in the slurry is kept to a minimum by the use of deflocculants and the solids content is made as high as possible. Since the mold is porous, water is absorbed from the slurry into the plaster and a layer of solid material is deposited on the mold surface. The thickness of the layer depends on the length of time the casting process is allowed to proceed. Either solid or hollow ware may be produced by this means. If hollow ware is desired, the residual slurry is simply poured from the mold after the desired wall thickness has built up. Highly irregular shapes may be produced by this means, but there are

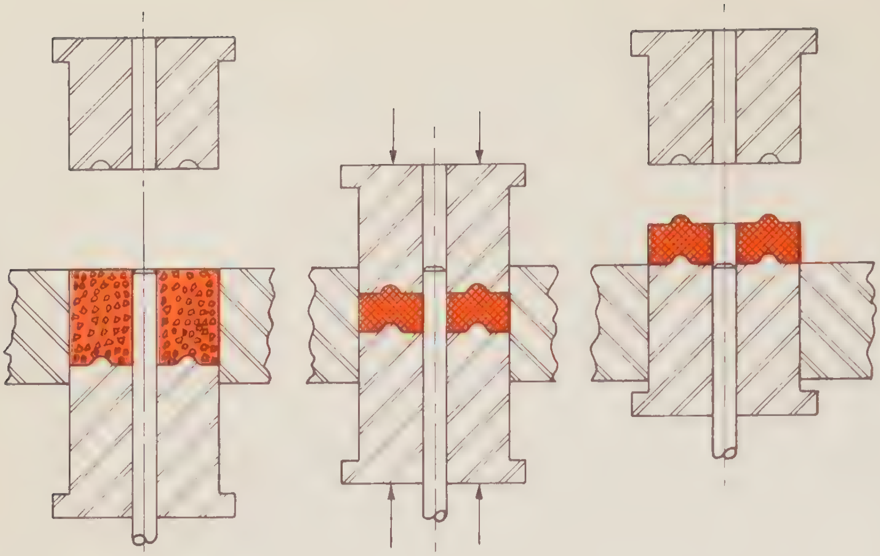


Fig. 3—In the formation of ceramic ware by pressing, granular material is fed into the open die cavity (left). The die is closed and pressure is applied from both top and bottom (center). The top punch is lifted, and the part ejected by the bottom punch (right). The length to area ratio of parts made by this process generally is small (Fig. 4).

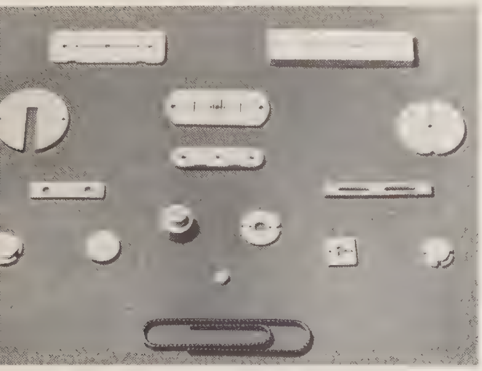


Fig. 4—These are typical small ceramic parts manufactured by pressing.

obvious limitations. As water is absorbed by the mold the part being formed shrinks. The geometry of the piece, therefore, must be such that the part shrinks away from the mold and not around it. Undercuts or deep grooves in the mold surface cannot be used. The casting process is most often employed to produce relatively large shapes, particularly hollow or non-symmetrical parts that cannot be readily machined (Fig. 8).

Often secondary forming operations such as turning, boring, tapping, counterboring, threading, or grinding, are employed in conjunction with each of the above methods. These secondary operations permit the part to have a more intricate or more suitably finished contour than is feasible when only the primary forming operation is used. Obviously, such secondary operations are to be avoided if possible since they increase the cost of the product.

Other Methods

In addition to these four traditional processes, certain other methods of fabricating ceramic ware are available. These are methods in which resins of one form or another are used as temporary binders and the forming methods are similar to those employed for plastics. Where such methods are used, ceramic materials are mixed with a relatively large amount of organic, plastic material—on the order of 10 to 20 per cent by weight. The mixture is formed using machines similar to those employed by the plastics industry for injection molding, compression molding, or transfer molding. During subsequent firing operations the plastic portion of the batch is destroyed, leaving the ceramic in the desired shape. Under proper conditions, very intricate shapes may be produced by this means.

Dimensional Control Achieved Through Uniform Processing

Ceramic ware of the type listed in Tables I and II is subjected to a firing operation after forming. It is during this phase of processing that the chemical and physical reactions occur which give the material its characteristic properties. Partial fusion or sintering of the raw materials takes place with a consequent shrinkage and consolidation. The extent to which the firing operation is continued determines both the amount of shrinkage and the degree of porosity remaining in the part. At the same time, the extent to which reaction will occur at a given firing temperature depends on both the raw materials involved and the processing treatment they have received. Variations in either factor might lead to variations in shrinkage with subsequent unpredicted changes in fired size. In most cases, firing is carried to the point where complete vitrification is achieved, that is, until there are no remaining open pores and the ware has shrunk to its minimum volume. However, the desired properties are sometimes achieved at some prior stage, such as in the case of the materials listed in Table II.

The amount of shrinkage which takes place in the ware during firing may vary over a wide range but, in most cases, it falls between 10 and 17 per cent on a linear basis. The resulting large volume change poses a serious problem in dimensional control. Not only must tooling be made oversize to allow for the decrease in size during firing, but the ware must also be appropriately supported so that warpage, distortion, or breakage do not occur beyond tolerable limits.

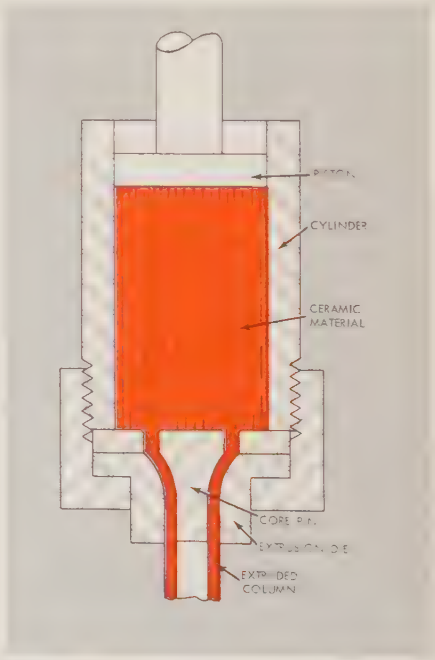


Fig. 5—This schematic diagram illustrates the extrusion process for forming ceramic parts. Plastic ceramic material is placed in the cylinder. Pressure applied by a piston forces the material through a restricted die section, forming a column having the cross section of the die. Core pins may be mounted within the die to produce an axial hole or holes, but the cross section must be symmetrical.

A striking example of what can be done in fabricating ceramics is a C-Stellarator chamber recently manufactured by a commercial supplier of alumina ware. This hollow chamber, made by slip casting, was nearly 2 ft in diameter and 4 ft long, with a tolerance of a thousandth of an inch on the finished piece. Obviously, this was not an everyday undertaking, yet it does serve to illustrate what can be done with ceramic materials. Shapes that can be produced with virtually any other material can be made of ceramic, with equally good surface finish and dimensional tolerance. This should not be construed to mean that high precision results without effort or cost. Rather, it is intended to indicate that ceramics are not necessarily limited to non-precision applications.

The standards for dimensional tolerance in ceramic ware are almost uniform throughout the industry, as well as the concepts of satisfactory design. For ware on which no post-firing finishing is done, a tolerance of ± 1 per cent, but not less than 0.005 in., is required. Surface finishes on the order of 20 to 25 RMS microin. are commercial. For glazed ware ± 2 per cent, but not less than $\frac{1}{64}$ in., is needed. These provide a starting point. By special grinding or lapping techniques, tolerances of ± 0.0002 in. can readily be produced, and surfaces can be finished to a range of 2 to 5 RMS microin. The cost of such finishing is a direct function of the complexity of the part and of the hardness of the ceramic itself.

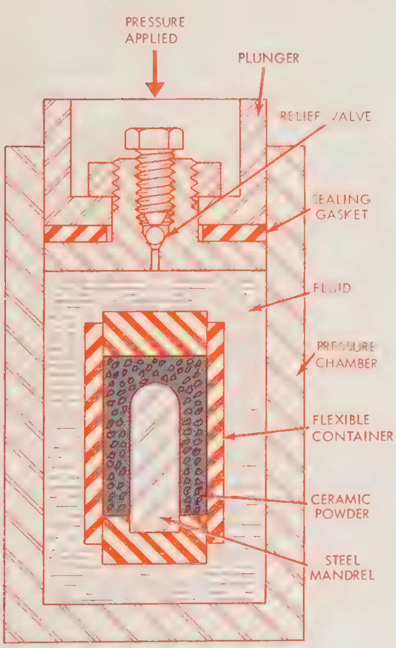


Fig. 6—In one method of isostatic molding, ceramic molding powder is confined within a flexible container. A metal mandrel to produce an internal cavity in the molding is shown inside the container. The container is compressed by hydraulic pressure, compacting the material into a self-sustaining blank. After removal from the mold, the blank generally is machined on the outer surface to produce the desired finish and contour.

Fig. 7—The slip casting process begins by pouring a water slurry of ceramic material into a porous plaster mold. After the slurry is poured into the mold, the water is absorbed into the plaster, depositing a layer of solids against the plaster wall. When the desired build up along the mold wall is attained, the remaining liquid is drained off. As it dries, the part shrinks from the mold, allowing removal.

Usually it is advantageous to design ceramic components first, using the simplest shape and broadest tolerances possible. Thereafter, metal parts that are more easily machined may be fitted to them at a lower over-all cost than if close tolerances are assigned to the ceramic part.

Some degree of warpage or camber invariably occurs during firing; hence, an effort should be made to minimize these effects. Thin walls in tubular shaped parts are to be avoided and wall thickness not less than 10 per cent of the diameter are recommended. Variations in thickness or level should be minimized.

Holes and counterbores located too close together or too close to an edge lead to distortion or cracking. Walls outside a hole usually should be at least equal in thickness to the hole diameter. Holes should be chamfered at the surface to minimize chipping. Where inside corners occur, they should be provided with a fillet to minimize cracking.

The roots of threads should be either flat or curved, not a sharp V. A Class 1 fit is commercially practical, although closer match can be provided either by selection or secondary finishing.

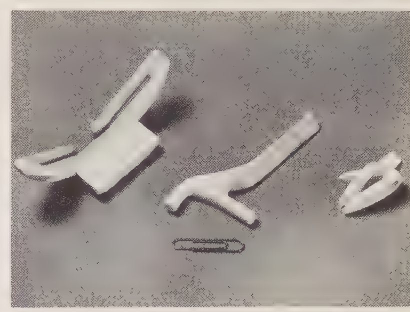


Fig. 8—These thread guides are typical products of the slip casting process.

Summary

As engineering materials, ceramics possess characteristics of stability, ruggedness, and durability that sometimes are hard to provide with plastics or metals. In addition, ceramics offer a variety of other desirable properties depending on the requirements of the application. For example, the properties of porosity, thermal expansion, or electrical conductivity can be provided in either high or low ranges depending on the material selected. But ceramics, like all materials, impose certain limitations on the user. For optimum performance of a ceramic product, the engineer not only should select the best material, but also he should apply it in such a manner as to take advantage of its good features while minimizing its weakness. The following are two important considerations in the application of ceramic components:

(a) Ceramics are brittle materials. Thus, they do not deform plastically under stress before failure, except at very high temperatures. Their stress-strain curve is a straight line up to the breaking point. As a result, they fail from tensile stress and never from compression.

(b) While many of the means used to shape ceramic articles are similar to those used to shape metals, the over-all process is quite different. The geometry of a part has an important bearing on both its cost and its utility.

Sensitive Nuclear Techniques Aid Study of Gyroscope Microsyns

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Contained within the gyroscope used in an inertial guidance system built at AC Spark Plug Division's Milwaukee Operations are two electromagnetic devices called *microsyns*. These complex, precision-built devices detect gyro motion and provide signals indicative of that motion. Recently, AC Spark Plug wished to evaluate the effectiveness of cleaning procedures used to remove grinding wheel grit and lapping compound from the bore of a microsyn, and to determine the presence and distribution of fluorolube compound impregnated into the microsyn assembly during gyro filling operations. Any residual grit or lapping compound which remains in the bore can affect the torque characteristics of a microsyn. Also, the penetration of fluorolube into voids or separations of the microsyn following filling of the gyro can cause changes in reaction torque. The problem of making the evaluations was presented to the GM Research Isotope Laboratory to see if nuclear techniques could be applied. A technique was developed using a radioactive grinding wheel and radioactive lapping compound to evaluate the cleaning procedures. Autoradiograms were used to determine the location and relative extent of fluorolube penetration within a microsyn assembly.

The problem: study factors affecting torque characteristics of microsyn assemblies

An important component of a guided missile is the small, high performance gyroscope. This gyro must be capable of withstanding severe environmental conditions while maintaining satisfactory inertial reference characteristics.

One example of such a gyro, built by AC Spark Plug Division at its Milwaukee Operations, is a floated, single degree of freedom, viscous damped gyro with essentially zero elastic restraint (Fig. 1). A missile may use three pendulous integrating gyros (P.I.G.) and three inertial reference integrating gyros (I.R.I.G.) in its guidance system. The P.I.G. senses acceleration. The I.R.I.G. senses rotation of the missile about its pitch, roll, or yaw axes.

On each end of a spherical float assembly (gimbal) contained within the gyroscope housing is the rotor of an electromagnetic device called a *microsyn* (Fig. 2). The two microsyns provide a means for detecting angular rotation of the float assembly and for introducing a controlled angular torque. Because of the functions the microsyns perform, they are referred to as the signal generator microsyn and the torque generator microsyn, respectively. Each microsyn also provides a radial magnetic balanced force for centering its rotor. This is used to supplement a liquid suspension system and to reduce friction of the float pivot bearing to a minimum.

The signal generator microsyn produces an output signal voltage when its rotor is rotated from a position which is fixed with respect to its stator. This output voltage signal represents the angular deviation of the case of the gyro unit from a reference direction in inertial space.

The basic function of the torque generator microsyn is to correct for any unbalances in the completed spherical float assembly. This microsyn applies a torque to the float assembly when an input current is applied and thereby prevents float rotation due to these unbalances.

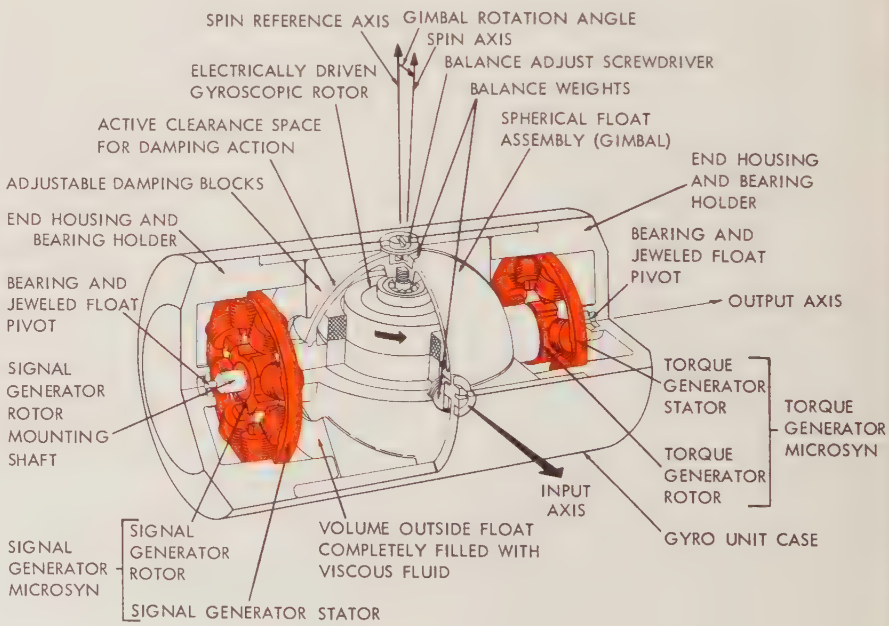


Fig. 1—Shown at the right is the integrating gyro unit used in an intermediate range ballistic missile. The gyro is a floated, single degree of freedom, viscous-damped gyro with essentially zero elastic restraint. A synchronous hysteresis motor drives the inertial element (gyroscope rotor) at constant speed, providing the source of angular momentum. The gyro rotor is supported by elastically loaded ball bearings. The bearings are coupled to a structure that functions as a gimbal support for the rotor and also serves as a hermetically sealed chamber, called the float. This float is immersed in a high density, high viscosity fluid for buoyancy and damping. On each end of the float is the rotor of an electromagnetic device called a *microsyn*. The microsyns provide a means for detecting float angular rotation and for introducing a controlled angular torque. They are, therefore, respectively referred to as a signal generator microsyn and a torque generator microsyn. In this sectioned view, only a portion of the microsyn assembly is shown—the generator stators, or cores, with the wound coil around each pole, and the rotors.

The guidance system requirements dictate that the summation of fixed unbalance torques acting about the output axis of the gyro must be less than two dyne-centimeters (1.4752×10^{-7} lb-ft).

Why Radioisotope Techniques Were Applied

During the manufacture and assembly of a microsyn there are three significant operations performed that produce conditions which may affect the torque characteristics of a microsyn.

The first condition results from a grinding operation performed prior to assembly of the gyro unit. The bore of a microsyn is ground to give the stator pole faces the required radius and curvature. Following the grinding operation, the bore of the microsyn is cleaned to remove grinding wheel grit. The cleaning procedure must be very effective. Because the jeweled float pivot is positioned in the center of the bore, any grit which remains in the bore could find its way to the pivot area and cause an excessive change in torque.

The second condition is the result of the lapping of stator pole faces. This lapping operation is part of an electromagnetic balancing procedure performed just before the microsyn is assembled into the gyro unit. Any unsymmetrical conditions which occur during the manufacture of a microsyn, up to the point of final assembly, can be corrected by lapping appropriate stator poles. The lapping operation removes some of the metal of the core which changes the magnetic flux and, consequently, the reaction torque value. After the pole faces have been lapped, the bore is cleaned of residual lapping compound. As in the case of the grinding operation, the cleaning procedures used to remove this residual lapping compound must be very effective. Any lapping compound remaining in the bore may affect the torque characteristics of the microsyn.

The third condition results after the microsyns are assembled into a gyro unit. The case of the gyro unit is then filled with fluorolube* under vacuum (10 microns) followed by a 100 psi pressure. The purpose of the fluorolube is to suspend the spherical float assembly within the gyro case and to provide viscous damping. The microsyns and other components inside the gyro case are surrounded by the fluorolube. Any voids, cracks, or separations in a microsyn assembly into which fluorolube can penetrate following filling of the gyro can cause reaction torque changes. These voids could be especially critical at the location of the coils on the pole pieces. Fluorolube penetration into the microsyns could conceivably alter the precise relationship between the coil and its corresponding pole. This would result in an unbalanced magnetic field and deleterious gyro performance.

To determine the possible areas of fluorolube penetration within a microsyn assembly is a difficult problem. Also, to evaluate the effectiveness of the cleaning procedures used to remove the grinding wheel grit and lapping compound is equally difficult. Any grit or compound remaining in the bore is in the microgram range.

The problem, therefore, of determining the possible presence and distribution of fluorolube penetration within a microsyn assembly and the effectiveness of the cleaning procedures was presented by AC Spark Plug Division to the General Motors Research Isotope Laboratory to see if nuclear techniques could be applied. Preliminary study indicated that the high sensitivity of radioisotopes could be used in solving this problem. The work which followed was a cooperative project between AC Spark Plug and the Research Isotope Laboratory.

*Fluorolube is a high polymer viscous oil made by polymerizing monochlorotrifluoroethylene.

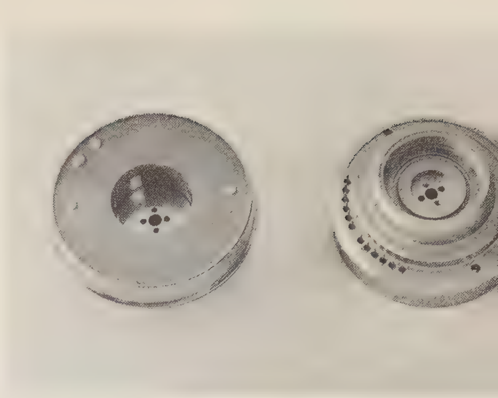


Fig. 2—The microsyn assembly is potted in an epoxy resin. At the left is a view of the front end of the microsyn assembly. This is the end which faces toward the spherical float assembly (Fig. 1). At the right is shown the back of the assembly. Also encapsulated in the beryllium housing of the assembly are electrical contact pins, a magnetic shield, and a printed circuit board.

Autoradiograms Used to Determine Fluorolube Penetration

Two microsyn assemblies were used in the study made to determine the spatial distribution of fluorolube throughout a microsyn. Both were impregnated with radioactive fluorolube. The microsyns then were sectioned and autoradiograms made to determine areas of fluorolube penetration.

The autoradiographic technique often

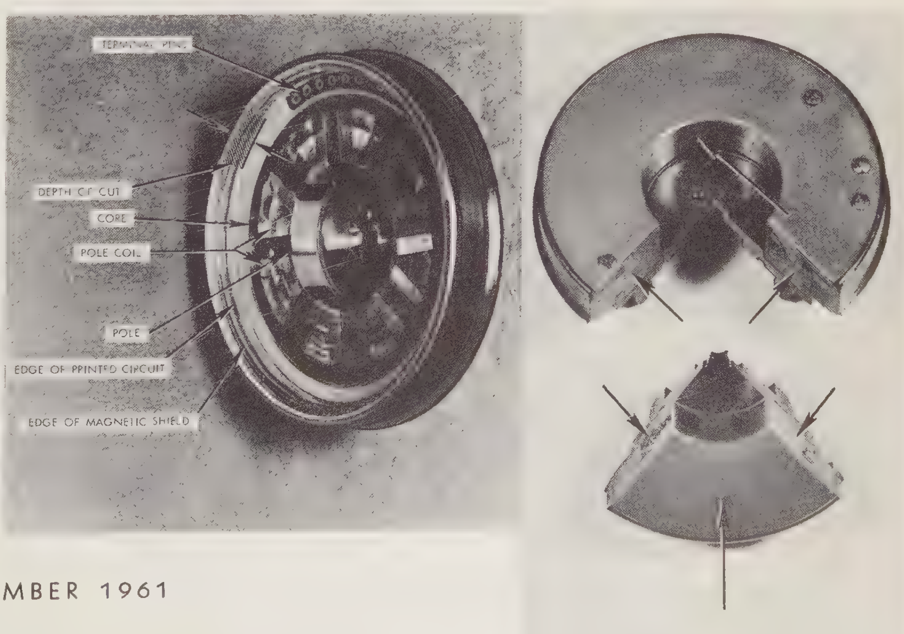


Fig. 3—The two microsyns used in the study to determine the penetration of fluorolube within a microsyn assembly were sectioned and autoradiograms then made of the sectioned surfaces. One microsyn assembly (right) was turned on a lathe and its surface machined perpendicular to its axis. This operation removed the epoxy resin and other materials within the beryllium housing until the tops of the steel pole pieces were just exposed. The cross section of the copper coils and the transversing terminal pins also were exposed. The other microsyn (far right) was sectioned pie fashion to remove a wedge. This sectioning operation was accomplished by sawing with a six-inch diameter aluminum oxide cut-off wheel. The arrows indicate the surfaces examined by the autoradiographic technique. These surfaces included the flat horizontal surface, the peripheral bore surface showing the pole faces, and the radial cross sections at various positions with respect to the poles and coils.

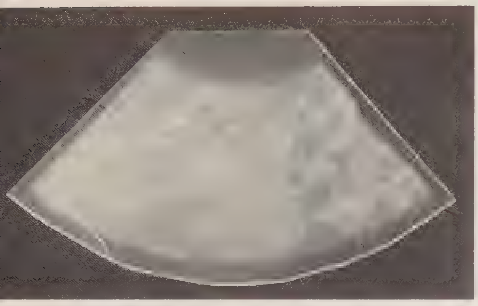


Fig. 4—An autoradiogram made of the horizontal surface of the wedge section cut from a microsyn assembly indicated a non-uniform distribution of activity over the entire epoxy resin surface. This was probably due to surface adsorption of the fluorolube. The autoradiographic exposure in this case was 144 hours on Kodak Type M industrial film.

is the only method for describing the spatial distribution of radioactivity within an object. Basically, the technique consists of placing an appropriate photosensitive emulsion in contact with a radioactive specimen. The contact time is made long enough to obtain the formation of a latent image due to the ionization produced in the emulsion by the beta and/or gamma eminations. In most cases, the emulsions are processed according to standard photographic procedures. The film types used in the microsyn study normally had two emulsions, one on each side of the film base. To increase the detail and contrast of the finished autoradiograms of the microsyns, one emulsion (that farthest from the specimen during exposure) was removed after processing.

The fluorolube was made radioactive by adding radioactive triphenylstibine [$Sb^{124}(C_6H_5)_3$] to 125 ml of the fluorolube compound. The triphenylstibine was dissolved in toluene. Two ml of this material dissolved in the fluorolube gave a specific concentration of approximately two microcuries per ml of fluorolube.

Preliminary experiments showed that triphenylstibine was non-volatile and would remain in the fluorolube under the temperatures and pressures to be used in the study. The decay schemes of the antimony isotopes, with an abundance of beta and low energy gamma eminations, indicated that the material would be suitable for autoradiographic studies.

The two microsyn assemblies used in the study were evacuated simultaneously in a vacuum system for 110 hours at 2×10^{-6} millimeters. The microsyns were evacuated to remove any gas or other volatile materials which might be present. An aluminum chamber containing the 125 ml of radioactive fluorolube was degassed for 2½ hours at a temperature of 170F and a pressure of from 20 to 40 microns. One of the microsyns was removed from the high vacuum system and placed inside the chamber on a special holding fixture positioned above the fluorolube. The aluminum chamber with the microsyn positioned above the fluorolube was degassed for one hour at a pressure of 15 microns and a temperature of 170F. The microsyn was then dropped into the fluorolube and evacuated for three more hours at a pressure of 40 microns. The aluminum chamber was then returned to atmospheric pressure and pressurized with nitrogen at 100 psi for 16 hours with a fluorolube temperature of 120F.

The same procedure was used to impregnate the remaining microsyn assembly. The pressurization with nitrogen, however, was carried out with a fluorolube temperature of 170F.

Following the impregnation procedure, the microsyn assemblies were cleaned with Freon to remove fluorolube from their surfaces. They were then sectioned to allow autoradiograms to be made of those areas of interest with respect to possible fluorolube penetration. One microsyn was turned on a lathe and its surface machined perpendicular to its axis (Fig. 3—left). The remaining microsyn was sectioned to remove a ¼ wedge (Fig. 3—right).

The sectioned specimens were covered with a thin plastic wrapping material before the photosensitive emulsions were applied. This was done to protect the emulsions from possible chemical reaction

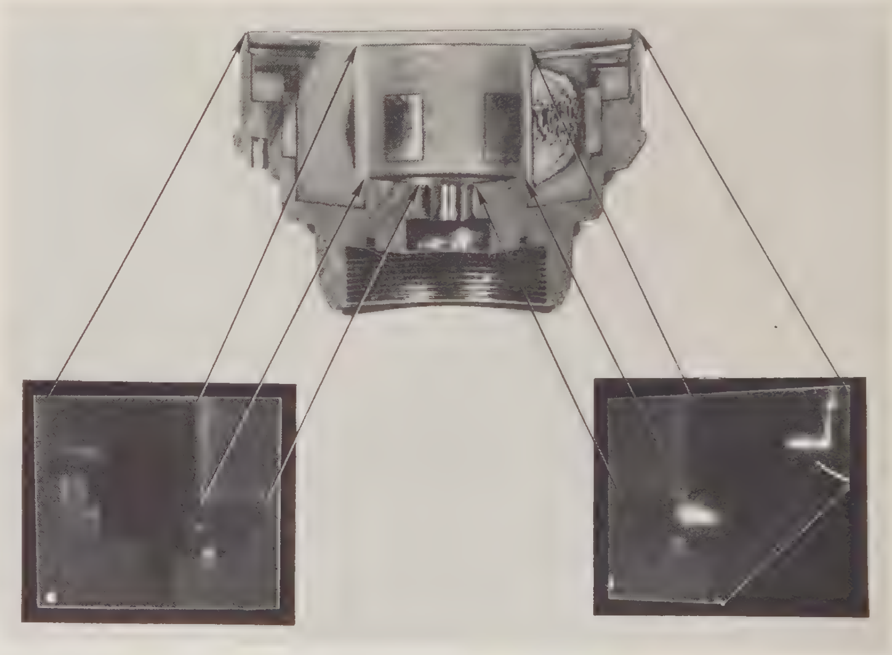


Fig. 5—Shown here are two additional autoradiograms made of the wedge section. The autoradiograms were made of the exposed vertical surfaces left by the radial cut. The autoradiogram on the left is a single emulsion, 16-hour exposure made on Kodak No-Screen film. The autoradiogram on the right is a single emulsion, 240-hour exposure made on Type M film. The comparative graininess of the faster No-Screen film (left) is readily seen. The silhouette effect shown in the autoradiograms was produced by the surface activity striking the film except where the film was shielded by the wedge section. The silhouette effect aided in further interpretation of these autoradiograms. Fluorolube penetrated between the beryllium housing and the epoxy resin to at least the point of contact of the housing with the steel core of the poles. Penetration also occurred at the bottom of the bore, which is the other exposed metal-plastic interface. In this case, the lateral penetration was not as great. The apparent smear of activity at this point in the right hand autoradiogram was due to the oozing of fluorolube beneath the plastic wrapping material used to protect the emulsion from chemical reaction with the microsyn surface during exposure. There was no evidence (right) of fluorolube in the exposed portion of the pole coil. The amount of impregnated fluorolube did not appear to be constant at different positions of the microsyn section.

Fig. 6—The wedge section was recut to expose the lateral surface of the pole. The autoradiogram of the recut wedge was exposed for 120 hours on Kodak Type AA film. One emulsion was removed. This autoradiogram was exposed to produce a film density about three times that of the right hand autoradiogram shown in Fig. 5. The increased film density was sought because of the lesser amount of activity expected in the coil region. No activity, however, was seen in this region. The autoradiogram of the recut wedge again demonstrated the areas of penetration shown in Fig. 5. However, the penetration down and under the core (between the core and the beryllium housing) was definitely visible. The areas of penetration are indicated by the small arrows shown in the view of the recut wedge at the top. Some fluorolube also is apparent beneath the magnetic shield. It is noticed, however, that a separation occurred in the top portion of the microsyn during the cutting operation. The activity shown, therefore, may be indicative of a bleedout phenomenon of fluorolube at the housing and epoxy resin interface. There was some loss of resolution in this autoradiogram because the cut left an uneven surface. This caused considerable separation between the film and the surface of the recut wedge.

with the materials of the microsyn or from fluorolube which might seep from the cut surfaces.

A Geiger survey had indicated the presence of some radioactivity over the entire surface of the microsyns. An autoradiogram was made of the epoxy resin surface of the wedge cut from the one microsyn (Fig. 4). This autoradiogram* revealed a rather mottled, low level distribution of activity over the entire surface. This was probably due to surface adsorption of the fluorolube.

Two autoradiograms were made of the wedge section (Fig. 5). These were of the exposed vertical surfaces left by the radial cuts. These autoradiograms showed that fluorolube had penetrated between the beryllium case and epoxy resin potting material. The penetration was to the point of contact of the case with the steel core of the poles. Penetration also occurred at the bottom of the bore, which was the other exposed metal-plastic interface. The autoradiograms showed no evidence of fluorolube penetration in the exposed area of the pole coil. The amount of impregnated fluorolube did not appear to be constant at different positions in the microsyns.

Since no fluorolube penetration was seen in the exposed area of the pole coil, it was decided to make another cut on the wedge section. This cut was made at an angle through the structure to expose the lateral surface of the poles. An excellent tapered exposure of the area of interest was provided (Fig. 6). The autoradiogram showed no activity in the coil region but did provide a definite indication of fluorolube penetration down and under the core. This was in the area between the core and the beryllium case.

Autoradiograms also were made of three surfaces on the remainder of the microsyn from which the wedge was cut (Fig. 7). The autoradiograms of the vertical surfaces exposed by the cut confirmed the findings shown by the autoradiograms in Fig. 5. The autoradiogram of the microsyn bore showed evidence of fluorolube penetration between the epoxy resin and the poles to varying degrees.

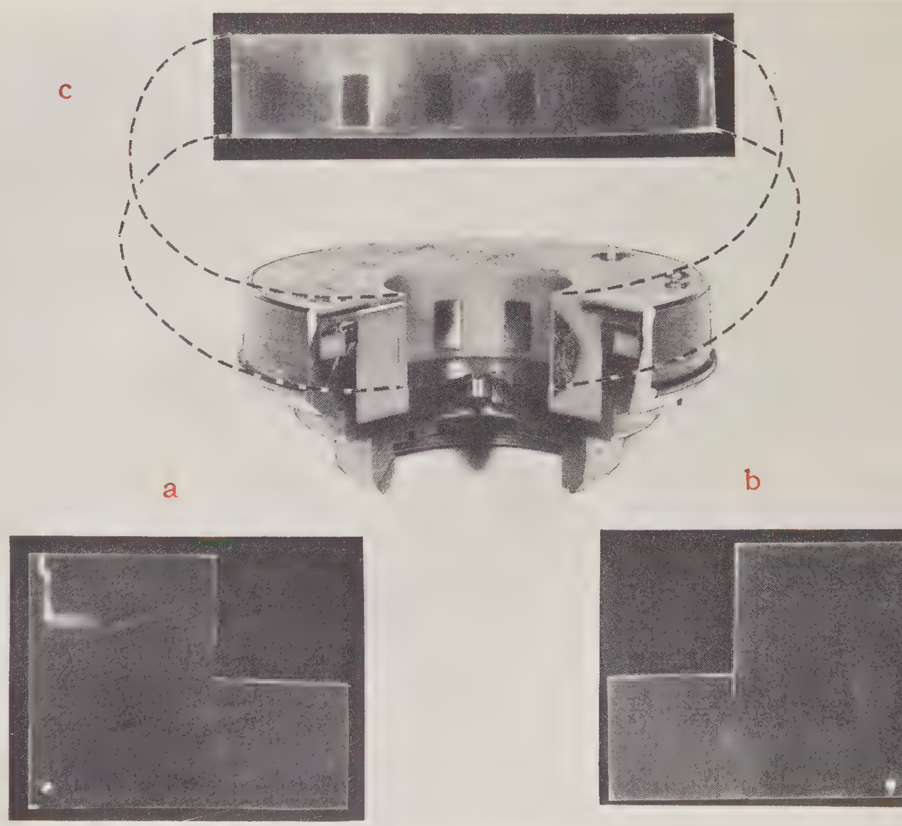


Fig. 7—Autoradiograms were made of the three surfaces on the remainder of the microsyn assembly from which the wedge was cut. Autoradiograms (a) and (b), which represent the vertical surfaces exposed by the cut, confirmed the findings illustrated in Fig. 5. Autoradiogram (a) matches the autoradiogram shown at the right in Fig. 5. The Type M single emulsion films used for autoradiograms (a) and (b) were exposed simultaneously for 240 hours along with the film of the microsyn bore (c). Autoradiogram (c) again demonstrated the overall, mottled activity on the epoxy resin surface of the microsyn. The autoradiograms showed evidence of fluorolube penetration between the plastic resin and the poles to varying degrees. The pole faces proper, however, showed no signs of penetration.

*The autoradiograms shown in Figs. 4 through 8 are reverse enlargements of the originals. Activity (radioactive fluorolube) is seen as white and the lack of activity as black.

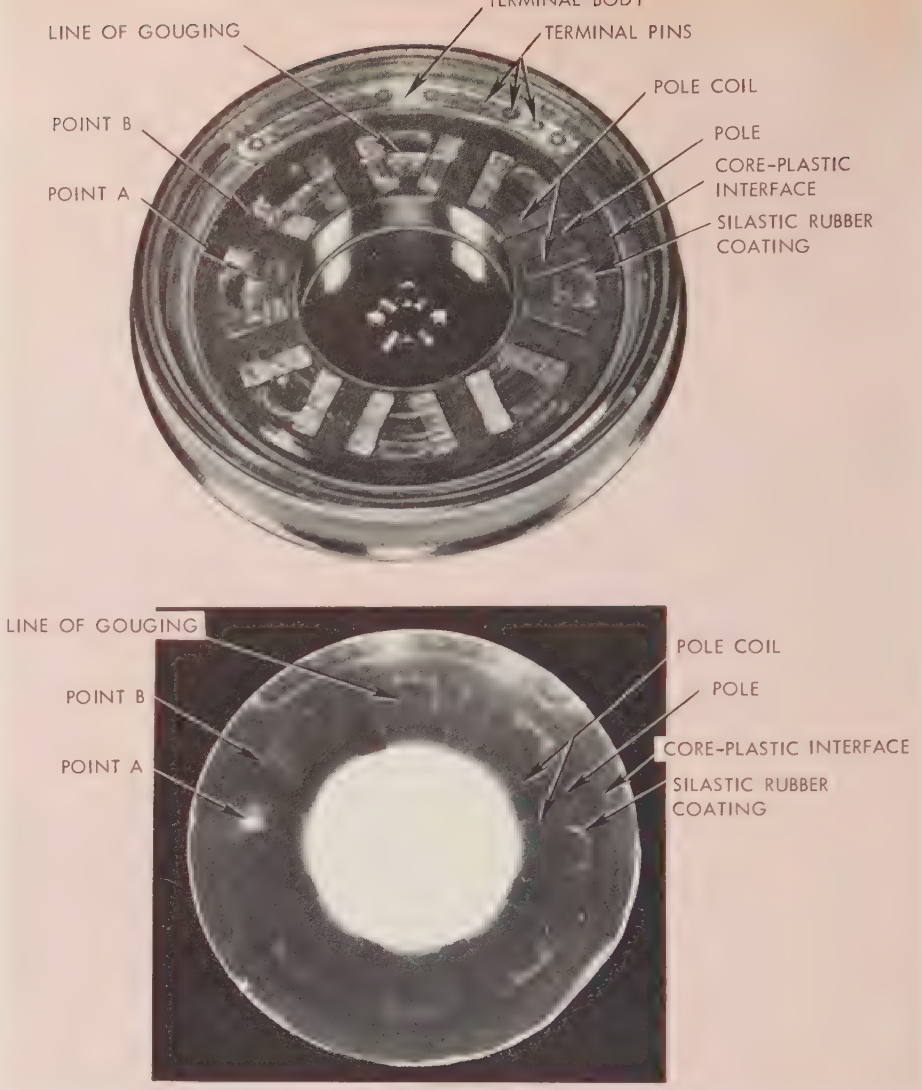


Fig. 8—The autoradiogram made of the machined surface of the microsyn assembly was a single emulsion, 336-hour exposure on Type AA film. In the photograph at the top showing the machined surface, the terminal pins terminate in the pin connectors on the back of the microsyn assembly. These pins, which are contained in a metallic structure called the terminal body, transverse the assembly to the printed circuit. The individual terminal pins are insulated from the terminal body by a layer of glass. Between the adjacent poles is a silastic rubber coating. The silastic rubber provides stress relief during the epoxy resin potting operation.

The autoradiogram showed penetration of radioactive fluorolube around every terminal pin, with two of the pins showing especially large amounts of penetration. No visible signs were seen to account for this. Penetration also occurred around the entire terminal body and some oozing of fluorolube was observed around each pin on the back side of the microsyn where they emerged from the housing.

The large white area in the center of the autoradiogram represents radiation from the vertical surface and base of the bore. The greatest amount of radiation in this case results from the fluorolube remaining on the base. This condition was found to exist over all surfaces of the microsyn case, as indicated by Geiger instrument inspections. Since the microsyn assemblies used for the autoradiographic examinations were given only a light brushing with Freon prior to sectioning, the surface retention of fluorolube probably was not significant.

Further examination of the autoradiogram revealed the presence of fluorolube along the sides of each pole. Also, a very distinct concentration of activity occurred at the interfaces between the epoxy resin and silastic rubber coatings. It was concluded that the route of this activity was between the outer wall of the beryllium housing and the epoxy resin and then along the core structure to the silastic rubber coating.

Other points of interest shown in the autoradiogram developed as a result of the machining operation. A line of gouging made by the cutting tool is shown in both the photograph of the machined assembly and the autoradiogram. This sudden, deeper cut opened the structures and allowed the escape of fluorolube, which had been driven into the assembly under pressure and had a tendency to ooze out at cut surfaces. This is again illustrated at points *A* and *B*. Here, the cutting tool pulled the coils out of position leaving a cavity in both places. At point *A*, which is adjacent to a silastic rubber coating, fluorolube bled into the cavity. At point *B*, which is adjacent to a pole, there is no activity at the cavity. The bobbin, which insulates the coil from the pole piece, retained the activity next to the pole and restricted bleedout from this site into the cavity. This fact supported the conclusion that any fluorolube entering the area of the silastic rubber coating or coils comes from below rather than along the pole surfaces.

The autoradiograms also indicated fluorolube at the interface between the epoxy resin and outer periphery of the core. This is shown by the white ring on the autoradiogram. The probable route of this activity was down the outer wall of the housing, then radially to the vertical surface of the core, and finally up the core surface.

The pole faces proper, however, showed no signs of penetration.

The final autoradiogram made in the study was of the microsyn assembly whose surface was machined (Fig. 8). Penetration was observed around every terminal pin and around the entire terminal body. Since these structures penetrate the first horizontal step of the beryllium case, which was previously shown to contain relatively large amounts of fluorolube (Figs. 5, 6, 7), this could be the origin of activity in the terminal pins and around the terminal body. Fluorolube also was observed along the sides of each pole. It was not known whether the fluorolube penetrated in from the bore (as indicated in autoradiogram (c), Fig. 7) or whether it came from material which had first penetrated between the case and plastic (Fig. 5). It was possible that there also could be a small amount of fluorolube in the coils. This faint indication, however, could be due to a smearing of activity during the machining operation from the sites of activity at the borders of the coils.

As a point of interest, the autoradiogram of the machined surface showed activity along such structures as the poles, core, and coils. The autoradiogram of the recut section of microsyn (Fig. 6), on the other hand, showed no activity in these areas. This was probably due to one, or all, of three reasons. First, a longer exposure time was used for the autoradiogram of the machined surface. Any minimal amounts of fluorolube in the recut section, therefore, might not have shown up in its autoradiogram which had a shorter exposure time. Secondly, some poles did not take up as much fluorolube along their walls as did others (autoradiogram (c), Fig. 7). Finally, it was possible that the machined microsyn adsorbed a greater amount of fluorolube than the microsyn which was sectioned.

Radioactive Grinding Wheel Used in Grit Retention Study

The grinding operation performed on a microsyn prior to assembly of the gyro unit consists of running a small grinding wheel around the bore to give the pole faces the required radius and curvature. Since the jeweled float pivot is positioned in the center of the bore of the microsyn, the cleaning procedures must be effective

Fig. 9—The grinding operations on the bore of the microsyns were performed inside a sealed glovebox to prevent the escape of radioactive material. The microsyn was secured in the chuck of a small model makers lathe (inset) and rotated at approximately 960 rpm. The irradiated grinding wheel was mounted on a spindle in a tool post grinder and rotated at 14,000 rpm. A light cutting oil was fed from a reservoir located on top of the glovebox. The grinding wheel was oscillated along the axis of the bore at approximately one oscillation per second. Two microsyn samples were ground for one minute each with a feed speed of 0.005 in. per minute to remove approximately 0.005 in. from the diameter of the bore.

to prevent the possibility of grit finding its way into this point to cause a change in torque. The standard production grinding operation, as performed at the AC-Milwaukee plant, was followed as closely as possible in the GM Research Isotope Laboratory.

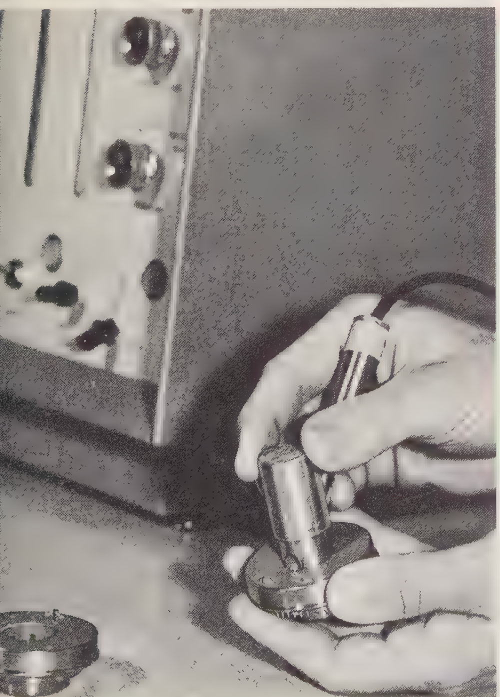
A radioactive grinding wheel weighing eight grams was used. The wheel was subjected to a 15-hour irradiation in a 2×10^{12} neutrons per cm^2 per sec flux at the Argonne National Laboratory reactor. The major radioactive constituent in the grinding wheel was sodium-24. There were approximately 10 millicuries of activity in the grinding wheel when used in the study. Small pieces of a broken grinding wheel were used as standards. These pieces were irradiated in the same package as the whole grinding wheel.

The grinding operations were performed inside a sealed glovebox to prevent the escape of radioactive material (Fig. 9). Following the grinding operations, the microsyns were washed in hot Varsol to remove oil, grit, and ground stock. This cleaning procedure was carried out inside a fume hood. One of the microsyns was given an additional cleaning in an ultrasonic cleaning unit using Freon as the solvent. The cleaning procedures were the same as those used at the AC-Milwaukee plant.

A special shielded counting device (Fig. 10) was constructed to inspect the bore of the microsyns for radioactivity after they were cleaned. To obtain quantitative data, a standard was prepared which could be counted with the same geometry and backscatter conditions† as any section of a microsyn bore. Several pieces of the irradiated broken grinding wheel were first pulverized with a mortar and pestle to provide a homogeneous sample. A small portion of the grit (7.4 milligrams) then was pressed onto a piece of plastic tape. The area covered by the radioactive grit was less than the area of the Geiger tube window (Fig. 10-b). A piece of plastic tape, 0.0006 in. thick, was used as a sealer over the radioactive grit to complete the standard sample.

When determining the specific activity of the standard, it first was placed in the bore of a microsyn assembly which otherwise was devoid of radioactivity. This was done to make sure that actual counting conditions would be duplicated. The standard was counted every time a microsyn was examined for radioactivity. This

†A radioactive material suspended in air will give a lower count rate than when it is backed up, for example, by a steel sheet. The environment influences count rate efficiencies. To eliminate errors due to varying conditions, standards are counted, whenever possible, under the same circumstances as the test specimens.



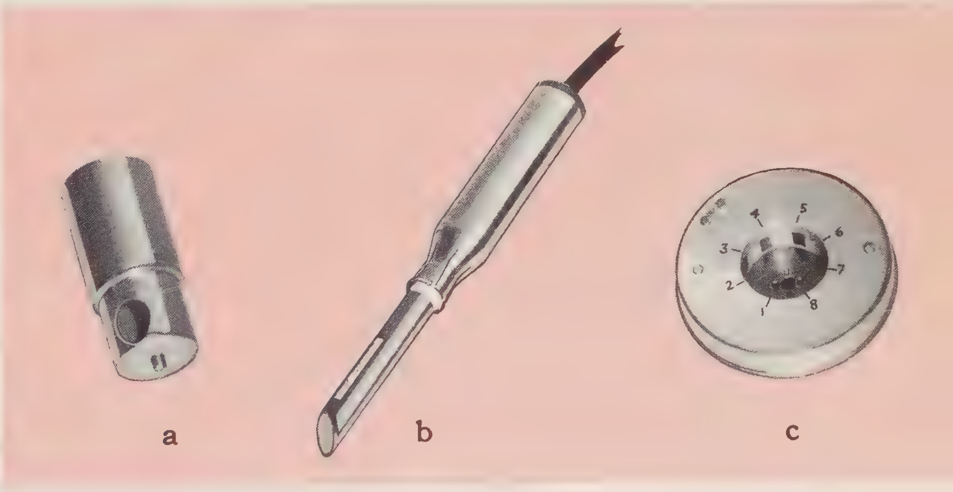


Fig. 10—The bore of a microsyn was inspected for radioactivity with the aid of a specially constructed shielded counting device. The device consisted of a lead plug shield (a) and an Anton No. 224 Geiger tube and connector (b). The area of the Geiger tube window was 0.248 sq cm. The bottom end of the Geiger tube, beveled to provide a 45° window, and the connector were held inside the lead plug by means of set screws. Numbers were inscribed on the microsyn assembly (c) at each pole location to provide reference points when collecting data. The lead plug was piloted in the jeweled bearing bore of the microsyn (left). The Geiger tube detector was indexed to examine one section at a time without interference by radiation from other sections of the microsyn. A cable ran from the Geiger tube connector to an electronic scaler, shown in the background in the photograph at the left.

RESIDUAL GRINDING WHEEL GRIT STUDY

MICROSYN 1X REGULAR VARSOL CLEANING STANDARD SPECIFIC ACTIVITY = 14.8 CPM PER GRAM			MICROSYN 2X VARSOL CLEANING FOLLOWED BY ULTRASONIC CLEANING IN FREON STANDARD SPECIFIC ACTIVITY = 12.6 CPM PER GRAM		
POSITION (POLE NO.)	NET COUNTS PER MINUTE	RESIDUAL GRIT (μ GRAMS)	POSITION (POLE NO.)	NET COUNTS (PER MINUTE)	RESIDUAL GRIT (μ GRAMS)
1	0	0	1	1	0.08
1 and 2*	5	0.34	1 and 2*	4	0.32
2	0	0	2	4	0.32
2 and 3*	3	0.23	2 and 3*	0	0
3	4	0.27	3	1	0.08
3 and 4*	4	0.27	3 and 4*	4	0.37
4	2	0.14	4	1	0.08
4 and 5*	4	0.27	4 and 5*	0	0
5	5	0.34	5	0	0
5 and 6*	0	0	5 and 6*	1	0.08
6	5	0.34	6	2	0.16
6 and 7*	0	0	6 and 7*	2	0.16
7	4	0.27	7	1	0.08
7 and 8*	5	0.34	7 and 8*	3	0.24
8	0	0	8	0	0
8 and 1*	4	0.27	8 and 1*	2	0.16

*INDICATES THAT THE GEIGER TUBE WAS POSITIONED TO COUNT THE PLASTIC AREA BETWEEN THE INDICATED POLES

Table I—Two microsyns, designated as 1X and 2X, were used in the study made to evaluate the effectiveness of the cleaning procedures applied in removing residual grinding wheel grit from the bore of the microsyns. After the bores of the two microsyns were ground to specific requirements, the microsyns were washed in hot Varsol to remove oil, grit, and ground stock. Microsyn 2X was given an additional cleaning in an ultrasonic cleaning bath using Freon as the solvent. Data were collected of the activity at each location (in counts per minute) and computations were made to show the weight (micrograms) of residual grinding wheel grit left in the bore of each microsyn. The data tabulated here show that, within statistical error, virtually no grinding wheel grit remained in the bore of either microsyn. Thus, the cleaning procedures were proven to be effective.

was necessary because of the relatively short half-life of the material (approximately 22 hours) and the presence of radioactive trace impurities.

The specific activity of the sample was defined as

$$SA_{std} = \frac{CPM_{std}}{W_{std}}$$

where

SA_{std} = specific activity of the standard

CPM_{std} = counts per minute of the standard

W_{std} = weight of the standard.

The weight W of the retained grinding wheel grit at each area of a microsyn bore was computed from

$$W = \frac{CPM_x}{SA_{std}}$$

where

CPM_x = counts per minute of the examined area.

The examined areas were identified by inscribed numbers on the microsyn at each pole location.

Data collected for the study showed that, within statistical error, virtually no grinding wheel grit remained in either microsyn bore (Table I).

Radioactive Lapping Compound Used in Cleaning Evaluation

Three microsyn assemblies were used in the study made to determine the effectiveness of the cleaning procedures used to remove lapping compound remaining in the bore after the pole faces are lapped. The study was performed using radioactive lapping compound. The compound, as obtained from the supplier, was irradiated in a flux of 2×10^{12} neutrons per cm^2 per sec for 15 hours at the Argonne National Laboratory reactor. Activation calculations indicated that the radioactivity produced in the lapping compound would be minimal. However, two of the radioactive isotopes—iron-59 and sodium-24—provided sufficient activity to carry out the study with adequate sensitivity.

The lapping operation was performed inside a glovebox (Fig. 11). The cleaning procedures were the same as those used at the AC-Milwaukee plant. Following the cleaning procedures, the pole faces and the plastic area between the poles were counted (Table II). The same shielded counting device was used as in the study for determining the effectiveness of cleaning procedures following grinding of the microsyn bore. To determine the number of micrograms of retained lapping compound, a standard was prepared in a manner similar to that used for the grinding wheel study. A known weight of lapping compound was placed on masking tape and then covered by a thin film of plastic material. This standard was counted with the same geometry as the sample under investigation.

The overall study indicated that signi-

Fig. 11.—The stator poles of a microsyn assembly were lapped inside a glovebox. A felt wheel, driven by a flexible shaft motor, was used to apply the radioactive lapping compound. Each pole in the microsyn assembly was identified by inscribing a number in the plastic surface immediately above its location.

RESIDUAL LAPPING COMPOUND STUDY

MICROSYN 1

POLE NO. 1 LAPPED
CLEANED WITH HOT VARSOL
RINSED IN FREON
STANDARD SPECIFIC ACTIVITY = 4.33 CPM PER GRAM

POSITION (POLE NO.)	NET COUNTS PER MINUTE	RESIDUAL COMPOUND (μ GRAMS)
1	46	10.6
1 and 2*	52	12.0
2	68	15.7
2 and 3*	65	15.0
3	26	6.0
3 and 4*	30	6.9
4	30	6 9
4 and 5*	44	10.1
5	26	6.0
5 and 6*	24	5.5
6	32	7.4
6 and 7*	22	5.1
7	16	3.7
7 and 8*	26	6.0
8	38	8.8
8 and 1*	50	11.6

MICROSYN RECLEANED
STANDARD = 4.03 CPM PER GRAM

POSITION (POLE NO.)	NET COUNTS PER MINUTE	RESIDUAL COMPOUND (μ GRAMS)
1	30	7.5
1 and 2*	51	12.7
2	46	11.5
2 and 3*	35	8.7
3	25	6.2
3 and 4*	30	7.5
4	34	8.5
4 and 5*	36	9.0
5	28	7.0
6	30	7.5
2**	45	11.2

MICROSYN 2

POLES 1 AND 5 LAPPED
CLEANED WITH HOT VARSOL
RINSED IN FREON
STANDARD SPECIFIC ACTIVITY = 3.86 CPM PER GRAM

POSITION (POLE NO.)	NET COUNTS PER MINUTE	RESIDUAL COMPOUND (μ GRAMS)
1	45	9.3
1 and 2*	41	10.6
2	30	7.8
2 and 3*	18	4.7
3	20	5.2
3 and 4*	17	4.4
4	26	9.8
4 and 5*	35	9.1
5	29	7.5
5 and 6*	28	7.3
6	14	3.6
6 and 7*	14	3.6
7	15	3.9
7 and 8*	28	7.3
8	16	4.2
8 and 1*	35	9.1

MICROSYN RECLEANED
STANDARD = 3.25 CPM PER GRAM

POSITION (POLE NO.)	NET COUNTS PER MINUTE	RESIDUAL COMPOUND (μ GRAMS)
1	35.5	10.9
2	27.6	8.5
4 and 5*	30	9.3
7 and 8*	19	3.9

MICROSYN RECLEANED IN ULTRASONIC CLEANING TANK USING FREON
STANDARD = 3.37 CPM PER GRAM

POSITION (POLE NO.)	NET COUNTS PER MINUTE	RESIDUAL COMPOUND (μ GRAMS)
1	31	9.1
2	29	8.5
4 and 5*	26	7.6
7 and 8*	15.3	4.5

MICROSYN 3

POLES 1 AND 5 LAPPED
CLEANED WITH PERCHLOROETHYLENE
STANDARD SPECIFIC ACTIVITY = 3.35 CPM PER GRAM

POSITION (POLE NO.)	NET COUNTS PER MINUTE	RESIDUAL COMPOUND (μ GRAMS)
1	38	11.7
1 and 2*	36	10.7
3	15.5	4.6
5	21.5	6.4
5 and 6*	16.5	4.9
7	6	1.8

*INDICATES THAT GEIGER TUBE WAS POSITIONED TO COUNT THE PLASTIC AREA BETWEEN THE INDICATED POLES
**FOLLOWING AN ADDITIONAL TWO MINUTE CLEANING IN AN ULTRASONIC CLEANING TANK

Table II—Summarized here are the results of the study made to determine the effectiveness of the cleaning procedures used to remove lapping compound from the bore of a microsyn assembly. Three microsyns were used in the study.

Microsyn No. 1 had only one pole lapped. After the microsyn was cleaned in hot Varsol at a temperature of 115F and rinsed with Freon, count rates and the weight of the residual compound were determined at all pole faces and in the area between the poles. The microsyn was then recleaned in hot Varsol, reanalyzed, and the weights of residual compound computed. The data showed that significant amounts of lapping compound remained on the surface of the bore, even after the microsyn was recleaned. The largest concentrations of compound were at the lapped pole and also on each side of the pole.

Microsyn No. 2 had two poles lapped. The two poles were approximately opposite each other. After count rates and residual compound weights were determined at all pole and between pole positions, the microsyn was recleaned, using the standard cleaning procedure of washing in hot Varsol and rinsing in Freon, and the data again collected. This time, however, data were collected at representative pole and between pole positions. Then, the microsyn was cleaned in the ultrasonic cleaning bath for four minutes. Data were again collected at the same representative positions. The overall data indicated that the greatest concentration of compound occurred just beyond the two pole faces which were lapped. This was where the compound built up ahead of the felt wheel used to apply the compound (Fig. 11). It also was apparent that the additional cleaning operations did not remove any more of the retained lapping material.

Microsyn No. 3 was lapped at the same two poles as microsyn No. 2. For microsyn No. 3, however, cold perchloroethylene was used instead of hot Varsol in the cleaning procedure. No improvement was observed in reducing the amount of residual compound using this cleaning procedure.

Information obtained from the overall study resulted in the adoption of a modified lapping operation which made possible more effective cleaning procedures.

ficant amounts of lapping compound remained in the bore of a microsyn after it was cleaned. The data collected, however, aided in establishing a modified lapping operation which permitted improvements to be made in the cleaning procedures.

Summary

The application of radioactive techniques to study the extent of fluorolube penetration in a microsyn assembly and to evaluate the effectiveness of procedures used to clean the bore of a microsyn proved highly effective in providing information which could not have been obtained by other means.

The use of autoradiograms indicated the spatial distribution of fluorolube within a microsyn assembly and pointed out specific areas where penetration existed. The information obtained aided in the development of new potting materials and methods for encapsulating the assembly.

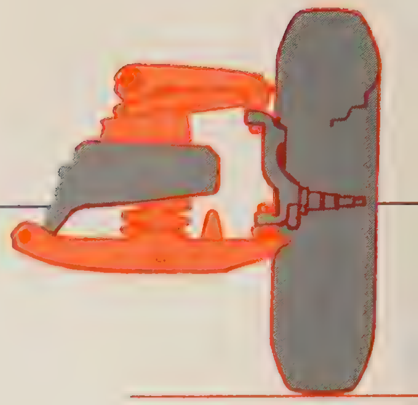
The cleaning procedures used to remove residual grinding wheel grit from the bore of a microsyn proved to be effective. The use of a radioactive grinding wheel to determine the amount of grit remaining in the bore after cleaning simplified the analysis to a great extent.

The study made to determine the effectiveness of cleaning procedures used to remove lapping material from the bore of a microsyn indicated that significant amounts of the material remained in the bore after cleaning. The amount of material remaining, which was from 7 to 64 micrograms per sq cm, seemed to be unaffected by the type of cleaning procedure used. The data obtained from the study, however, aided in the establishment of a modified lapping procedure which contributed to improving the effectiveness of the cleaning procedures.

Acknowledgment

The authors acknowledge the assistance of Thomas Turner, Jr., General Motors Research Laboratories, especially for his help in the sectioning and grinding of the microsyn assemblies.

A Design Summary of the Cadillac Front Suspension System



The design of a front suspension system is based on obtaining the optimum combination between the many variables which affect suspension performance and, in turn, the riding and handling qualities of a vehicle. In the design of the present Cadillac independent front suspension system, certain innovations were made to obtain definite design objectives. This was especially true in obtaining further improvements in ride softness and handling precision. Ride softness was obtained by providing additional deflection during impact input and orienting this deflection along the path of impact. A reduction in steering ratio, changes in front wheel geometry, and refinements in the power steering gear valve contributed to improvements in handling precision. Other features of the front suspension system include permanently packed spherical joints which eliminate the need for periodic lubrication, independent adjustment of camber and caster which simplifies front wheel alignment, and component interchangeability. The design of the present front suspension system also provided the opportunity to introduce various improvements in the braking system.

The design of the present Cadillac front suspension system resulted from a need to provide more space in the front of the chassis to accommodate a lower placement of the engine and to permit the brake drums to be moved to a more favorable location.

The objectives of the front suspension design and development program were to provide further improvement in suspension performance by improvements in ride softness, handling precision, and isolation of road noise. Additional design objectives were to simplify routine service operations performed on a suspension system and to effect a reduction in tooling costs through component interchangeability.

Rubber Bushings Used to Obtain Ride Softness

Ride softness varies directly with deflection. Handling precision, or the ability of the car to respond instantly and solely to the driver's input signal, varies inversely with deflection. The prime objective during the developmental phase of the front suspension system was to obtain the optimum combination of ride softness and handling precision.

One way to obtain a softer ride is to use a softly sprung suspension, that is, one which deflects vertically under light loads. Another way is to provide more deflection along the path of the loads encountered during impact. For example, a tire with a pressure reduction of four psi will be softer on impact and will deflect

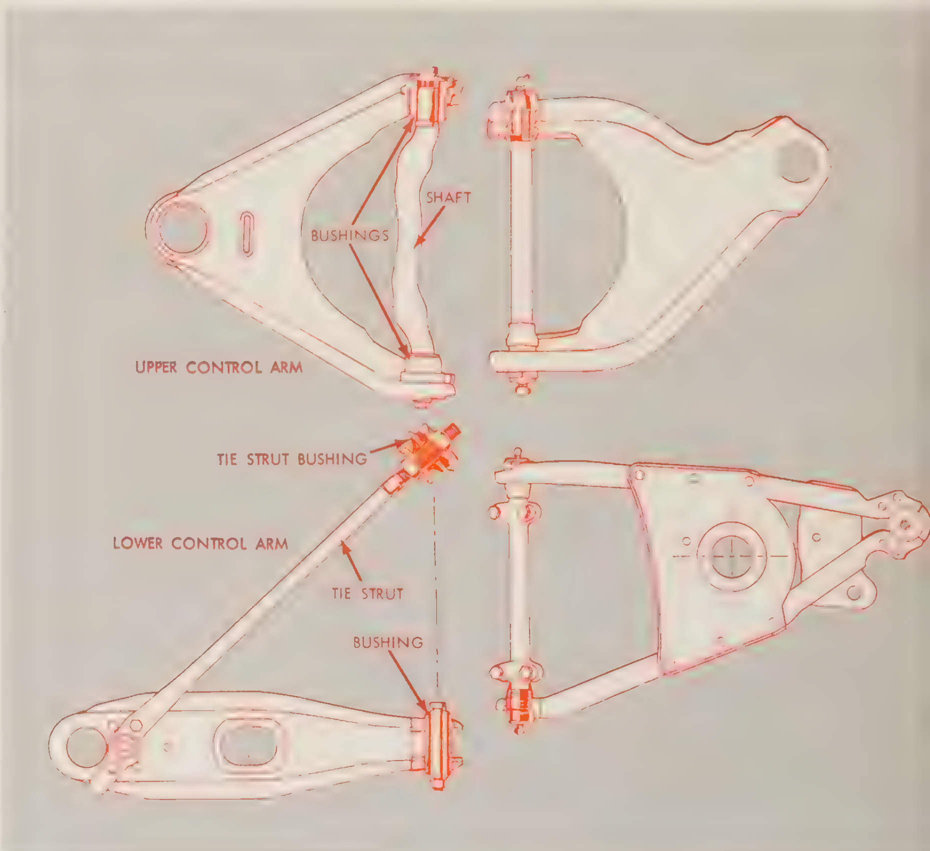


Fig. 1—Shown here, in plan view, is a comparison between the upper and lower control arms of the present Cadillac front suspension system (left) and the control arms of the previous system (right). The rubber bushings in the upper control arm are placed farther apart in the present design to reduce reaction loads at the frame during braking and impact and also to control suspension deflections in the modes of pitch (caster) and yaw (toe). The upper control arms pivot at their inner ends on the rubber bushings. These bushings are connected to a one-piece suspension arm shaft which, in turn, is bolted to the cross member of the frame. The lower control arms pivot on a single rubber bushing which also is bolted to the frame cross member. A diagonal tie strut is used between the lower control arm and cross member of the frame to carry the fore and aft load of the front wheels. The tie strut bushing deflects both axially and conically. Conical deflection is produced by the angular movement of the longitudinal axis of the bushing during vertical wheel travel.

By JOHN T. HOBAN
Cadillac Motor Car
Division

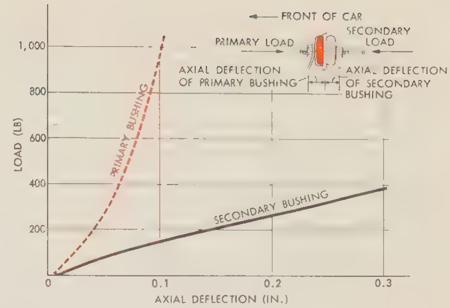
Design provides further improvement in ride softness and handling precision

more during impact loads than a tire inflated at a normal pressure. There are practical limits governing the extent to which a suspension can be softened or the tire pressure reduced. In the case of the Cadillac front suspension, too soft a suspension and too much reduction in tire pressure would have required the use of larger springs and tires to maintain the design stresses used with the materials for these parts.

Ride softness was obtained by designing additional deflection into the front suspension during impact input and orienting this deflection along the path of impact. The additional deflection was obtained by using rubber bushings in the upper and lower control arms of the suspension system (Fig. 1). These bushings, which help isolate road noise, were designed to provide deflection of the suspension system in the fore and aft mode. Unfortunately, deflection in the fore and aft mode also produced deflection in the other modes—yaw, roll, pitch, and lateral translation. This produced an adverse effect on the front wheel geometry, which was minimized by placing the bushings in the upper control arm as far apart as practical.

The critical bushing in the front suspension is the tie strut bushing (Fig. 1). It was found that when its deflections were controlled, less deflection was required in the bushings used at the other points in the suspension system. The importance of the tie strut bushing to the deflection-versus-load characteristics of the suspension (Fig. 2), both longitudinally and vertically, can be appreciated when its action during impact is considered. It not only deflects axially, but conically as well. Conical deflection is produced by the angular movement of the longitudinal axis of the bushing during vertical wheel travel. To produce a soft ride the resistance of the bushing to both axial and conical deflection was kept as low as possible.

Many types of tie strut bushings were evaluated during the developmental stages of the front suspension system (Fig. 3). Laboratory test equipment was designed to measure the relative reliability of the various bushings tested. This equipment cycled a bushing both axially and conically and could be adjusted to vary axial preload, axial stroke, axial



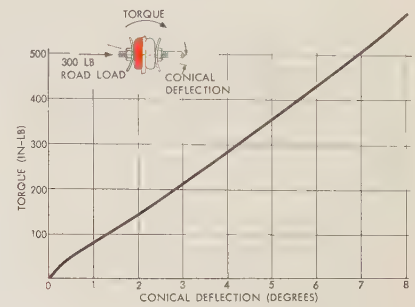


Fig. 2—The deflection-versus-load characteristics of the tie strut bushing assembly are shown in the curves at the right. The slope of a curve at any point indicates the bushing rate of the part in the mode indicated by that curve. The rate of axial deflection of the primary bushing (top) is three times that of the secondary bushing at road load. The road load is approximately a 300-lb axial load on the primary bushing. The dual rate feature of the tie strut bushing assembly plays an important part in softening impact. The conical deflection-versus-torque curve (bottom) shows how little resistance the tie strut bushing offers to conical deflection. In other words, the bushing has a low conical deflection rate, which also is necessary in softening the ride. The conical deflection rate, however, increases desirably as the axial load on the primary bushing increases, for example, when the brakes are applied.

Fig. 3—Shown below are various types of tie strut bushing designs tested and evaluated before the final design, shown at the top, was decided upon. This design shows the difference in shape between the primary bushing and the secondary bushing. The difference was necessary to produce the load and deflection characteristics shown in Fig. 2—top. The other bushings shown here were not used because they either failed to meet requirements of reliability and reasonable cost or they did not contribute to ride softness and handling precision.

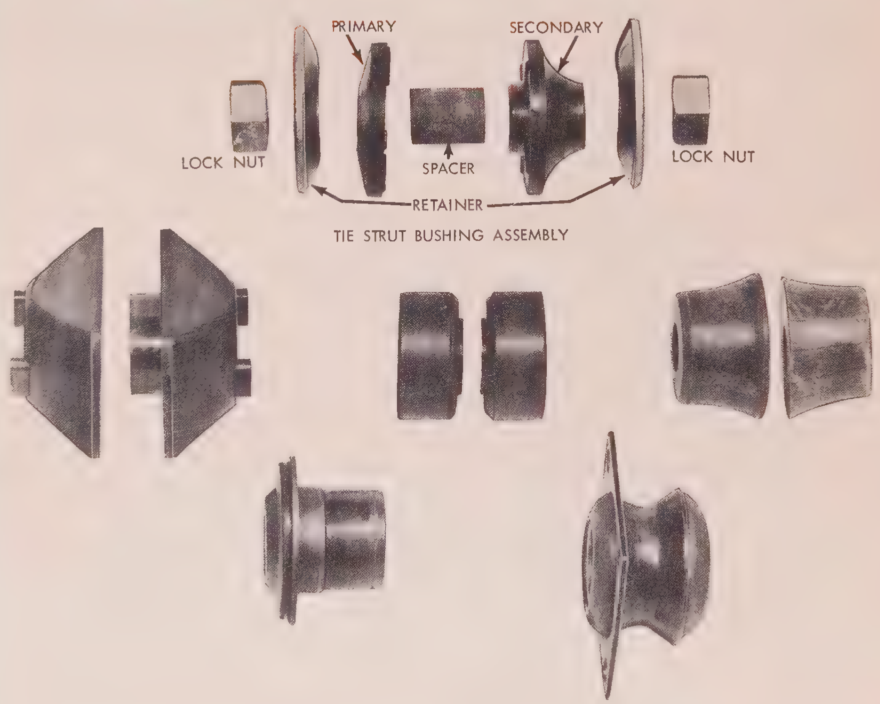


Fig. 4—Shown here is part of the instrumentation used by the GM Proving Ground to determine the deflection steer characteristics of the Cadillac front suspension system while it was under development. Deflection steer is the change which occurs in the front wheel geometry (caster, camber, and toe) during various road maneuvers. The angular difference between the two front wheels was measured by first transferring the angular position of the left wheel to a point on the backing plate of the right wheel by means of a modified drafting machine *A*. A flat leaf, strain gage transducer *B* was then used to measure the angular difference.

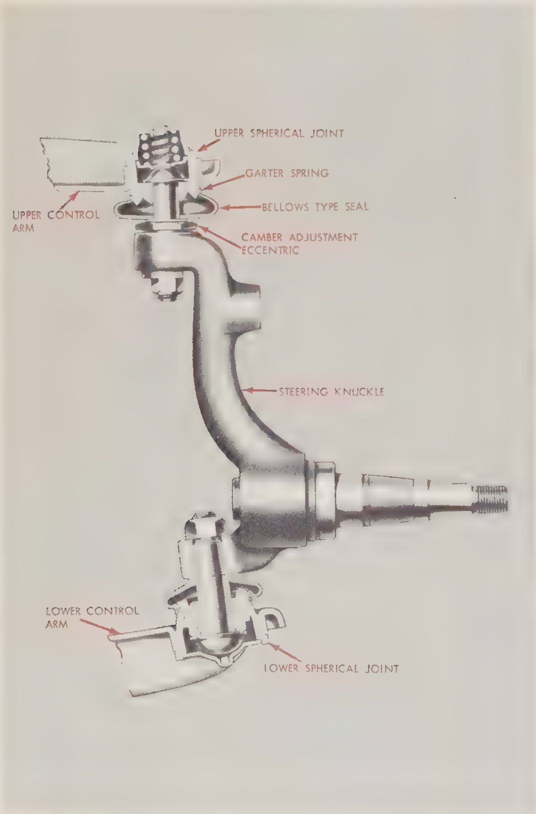


Fig. 5—The upper and lower spherical joints of the front suspension system, shown here in cross section, are pressed into their respective control arms. The upper spherical joint connects the upper control arm to the steering knuckle through a camber adjustment eccentric (Fig. 6). The lower spherical joint connects the lower control arm to the steering knuckle. Periodic lubrication of the spherical joints is eliminated by the use of a permanently packed joint. A single convolution, bellows-type seal is attached securely to the housing of the joint by a stainless steel garter spring. The joint is packed with a special, high-quality lubricant. Repacking of the joint is necessary only if the seal is damaged.

stroke cycle rate, conical deflection range, and conical deflection cycle rate.

Changes in Steering Ratio, Front Wheel Geometry Improve Handling Precision

Some problems occurred in handling precision during development of the front suspension system due to the deflections of the system's rubber bushings during cornering. Steering response was slower. Also, steering transition was affected due to a change of the front wheel geometry under cornering loads.

The slower steering response was compensated for by faster steering, that is, a lower steering ratio. The steering ratio was changed from 18.9 to 18.2. The problem of compensating for front wheel geometry change under cornering loads, however, was not as easily solved. It was necessary to determine the degree of geometry change during various road maneuvers (deflection steer). This work was carried out at the GM Proving Ground, where measurements were made of the deflection in camber, caster, and toe occurring in the front suspension (Fig. 4). The measurements provided the necessary data for making changes in the front wheel geometries for caster, camber, and toe.

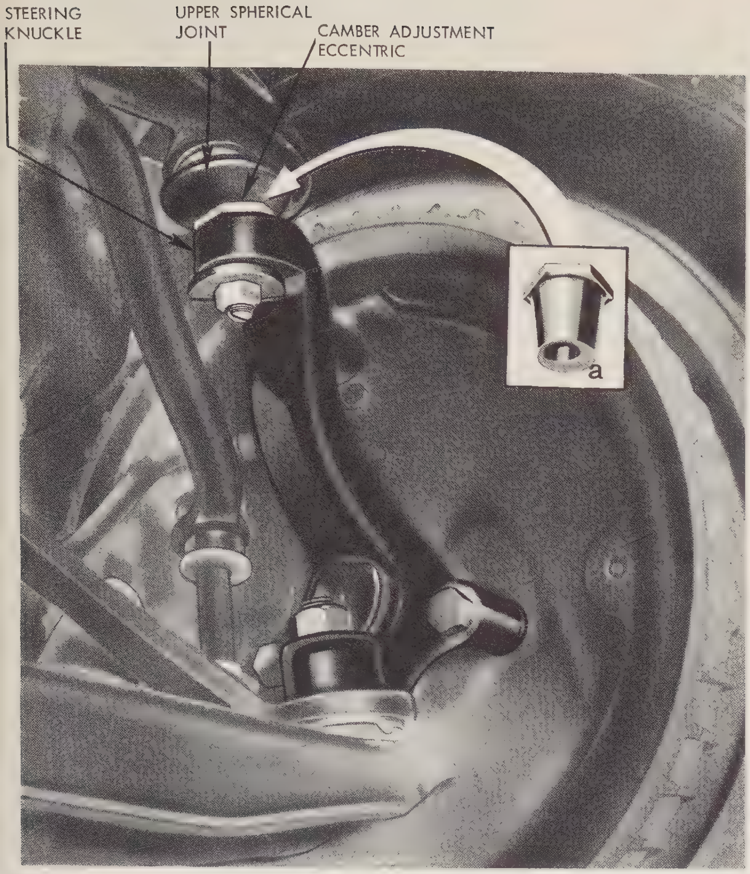
In addition to changing the steering ratio and the front wheel geometry, the handling precision and cornering ability were enhanced further by more sensitive valving in the power steering gear and greater flow in the power steering pump. These two changes gave added boost at a lower steering input torque. They also permitted a reduction in the diameter of the steering wheel from 17 in. to 16 in., which increased driver vision and allowed easier entry. The turning circle of the car also was reduced three feet by allowing the front wheels to turn at a greater angle in the wheel stop position.

Permanently Packed Joints Eliminate Periodic Lubrication

The objective of simplifying routine service operations was achieved by eliminating the need for periodic lubrication and by simplifying the procedure used to align the front wheels.

Lubrication

Since rubber bushings are used at all points of attachment of the suspension to the frame, lubrication is necessary only for the spherical joints of the suspension



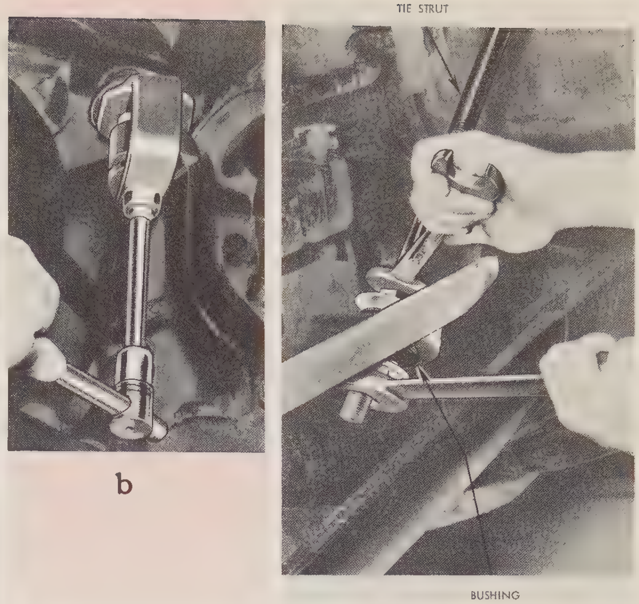


Fig. 6—The present design of the Cadillac front suspension system allows independent adjustment of camber (left) and caster (right). Camber is set by turning a camber adjustment eccentric (a) located between the stud of the upper spherical joint and the steering knuckle. The stud of the spherical joint is off center to the eccentric. Turning the eccentric by means of a special wrench (b) provides relative movement between the joint and the steering knuckle support. This movement affects the camber angle. The full turning range of the camber eccentric covers a camber change of $\frac{3}{4}°$ plus to $\frac{3}{4}°$ minus. Caster is changed by fore and aft adjustment of the lower control arm tie strut at the point of its attachment to the frame. Turning the retaining nuts on both ends of the tie strut bushings to move the tie strut forward increases positive caster. One full turn of the nut provides a $\frac{1}{2}°$ change in caster.

and for the spherical and pivot joints of the steering linkage (Fig. 5). The spherical joints are designed to allow both the up and down movement of the wheel due to road irregularities and the pivoting movement which occurs when the wheels are turned while steering.

Periodic lubrication for these joints is eliminated by a permanently packed joint. Repacking of a joint is necessary only if a seal is damaged and dirt or water enter the joint. In this event, a new seal and repacking are required. The sealed joint design not only eliminates the need for periodic lubrication but also insures a uniform performance of the joint throughout its service life.

Wheel Alignment

The design of the front suspension system eliminates the need to shim the control arms of the suspension to obtain the desired camber and caster setting. Unlike the previous shimming method, which affected both caster and camber, the present method allows independent adjustment of camber and caster (Fig. 6).

Camber is adjusted by turning an eccentric bushing fitted between the upper spherical joint and the steering knuckle. Caster is adjusted at the point where the lower control arm tie strut is attached to the frame. Toe-in adjustment is made in the conventional manner by means of a threaded adjuster in each tie rod.

Suspension Components are Interchangeable

Data obtained from laboratory and road tests of prototype suspensions provided information used for making changes as the final design of the front suspension system progressed to completion. Close liaison with the Cost Estimating and Purchasing Departments kept the Engineering Department up to date on the cost of each component as design changes were made. Guided by timely cost information, and with the coordinated efforts of design and development engineering groups, the additional design objectives of weight reduction, component interchangeability, and combined functions were attained.

The present Cadillac front suspension system is over 10 lb lighter than the previously used system. With the exception of the steering arms, all components of the system are interchangeable between the left and right side of the car. This interchangeability of components results in a direct savings in tool costs and indirect savings through inventory reductions both in the plant and in the field. Designing components to have combined functions also resulted in both a savings in cost and in weight. For example, the previous suspension design required a spring seat. The present design eliminated the need for a separate spring seat by having the seat embossed into the lower control arm.

Summary

The design objectives set forth in the planning and developmental stages of the present Cadillac front suspension system were attained. Significant improvements were made in ride softness, handling precision, and noise reduction. The overall weight of the suspension system was reduced and savings in tooling costs were realized by an interchangeability of component parts. Servicing requirements for the system were greatly simplified. Periodic lubrication is eliminated and wheel alignment is easier and is more precise. The suspension system also is compatible with an improved braking system.

What Does a Patent Cover?

By GERALD E. McGLYNN, Jr.
Patent Section
Detroit Office

A patent may be considered as a contract between the granting government, acting on behalf of the general public, and the inventor of the patented matter. Under the contract, the inventor discloses his invention to the public rather than keeping it a secret and, in return, is granted the right to exclude others from practicing the invention covered by the patent for a specified number of years.

Both the inventor or his assignee and the public are vitally interested in what a given patent does and does not cover, since the right to exclude extends only to that which is covered by the patent and the public is free to use everything else in the absence of another pertinent patent. How, then, is it determined what a patent covers? The answer to this question depends primarily on what the patent claims cover when read in the light of the description of the invention. However, like any other contract, the patent may be susceptible of different interpretations requiring consideration of the prior art or what had been done before the invention was made, and the proceedings conducted in the patent office to obtain the patent.

Principal Parts of a Patent

The applicable statutes require that every application for a patent, and hence any patent granted on such application, contain a complete description of the invention "in such full, clear, concise, and exact terms" as to enable others skilled in the particular art involved to practice it. Such a description must include at least one tangible example of how the invention may be practiced. Where inventions in the mechanical arts are involved, as compared to some chemical and metallurgical inventions, such an example ordinarily includes drawings illustrating specific details of a device or process which embodies the invention.

Furthermore, every patent must contain one or more claims "particularly pointing out and distinctly claiming the subject matter" which the inventor considers to be his invention, and such claims must be clearly supported by the description of the invention. Thus, the description of the invention contained in the patent forms the basis of the patent claims, and the claims constitute the inventor's description or definition of what is his under the patent—the metes and bounds of the area from which the public is excluded.

What the Patent Claims Cover

Since the inventor need not describe and illustrate all conceivable forms in which his invention might be practiced, the claims may cover considerably more than the details of the example or examples disclosed while still defining the invention embodied in such examples. On the other hand, if the invention resides primarily in the specific details of the example given in the patent, the claims should be limited correspondingly. Therefore, looking first within the four corners of the patent itself, it is necessary to determine what the claims literally mean, or could mean, when read in the light of the description of the invention. For example, in a patent disclosing a machine including a hydraulically operated piston and cylinder assembly, the claims to the machine might refer to the assembly as a "force-exerting means," or a "jack," or a "fluid pressure operated means," or a "fluid pressure operated means including relatively reciprocable piston and cylinder elements."

If the claims recite a "force-exerting means" or a "jack," they may literally cover another similar machine which uses an electrically operated screw-jack instead of the hydraulically operated piston and cylinder assembly specifically disclosed in the patent. But, if the claims recite a "fluid pressure operated means," they would not read literally on the other machine using the electrically operated screw-jack, and would not literally cover it.

In most instances, a patent is limited strictly to what is literally within the language of its claims. However, the scope of the claims may be affected by the *doctrine of equivalents*, the principle of law that a patent covers equivalents of what is claimed. Assuming that the electrically operated screw-jack in the other machine is related structurally to other elements thereof in substantially the same way, and functions in substantially the same manner to obtain substantially the same result as the piston and cylinder assembly in the claimed machine, the doctrine may apply and the claims *may* be construed beyond their literal meaning to cover the other machine. But perhaps they are not equivalents, or the recitation of the "fluid pressure operated means" is critical in defining an invention over the prior art. If so, the claims would not be extended beyond their literal meanings.

Prior Art and Patent Office Proceedings

After an application for a patent is filed in the Patent Office, it is usually the subject of considerable correspondence between the Patent Office Examiner and the attorney for the applicant. It is the Examiner's responsibility to allow only those claims which define something inventive over the prior art. It is the attorney's responsibility to obtain the broadest coverage possible in view of such prior art. Thus, the Examiner searches in his collection of prior patents and other publications to find the most pertinent prior art available. Perhaps the Examiner rejects one or more of the application claims on such art, and gives his reasons why. The attorney may disagree with the Examiner's position, and limit his response to arguments pointing out why the claimed matter is inventively different from the prior art. Or perhaps the rejected claims may be amended to include additional language more specifically defining the invention.

The prior art cited against the application and the exchanges between the Examiner and the attorney may be of considerable importance in determining what the resulting patent covers. For example, and again referring to the machine patent discussed above, assume that

an application claim defined the machine as including a "force-exerting means" or a "jack," and such claim was rejected on a patent showing a similar machine which included an electrically operated screw-jack instead of the piston and cylinder assembly of the patent. Assume also that the claim was then amended to more specifically recite the "fluid pressure operated means," coupled with an argument as to the advantage of such a means over the electrically operated screw-jack of the reference. These circumstances could invoke the *doctrine of file wrapper estoppel*, another legal principle to the effect that, once a claim is limited in view of prior art to secure its allowance, it cannot subsequently be enlarged to regain that which was surrendered. In other words, once the machine patent issues containing the amended claim, it would be strictly construed so as to exclude the electrically operated device. Hence, the *doctrine of equivalents* would not apply, and the other machine using the electrically operated screw-jack would not be covered by the patent.

It is also possible that the Examiner erred in allowing a claim in view of the art he found, or perhaps he overlooked some of the pertinent art. For example, assume that the prior art patent cited by the Examiner disclosed exactly the same machine as the patent in question, except for showing an electrically operated screw-jack instead of the piston and cylinder assembly. Also assume that the screw-jack and the piston and cylinder assembly actually were equivalents. Under these circumstances, even though the claims do not read on the reference patent because they recite a "fluid pressure operated means," the claims may nevertheless be invalid for lack of invention and legally cover nothing. Furthermore, the same result may be obtained if additional prior art is found disclosing an equally pertinent machine which does include the piston and cylinder assembly or equivalent "fluid pressure operated means."

Summary

What a patent does and does not cover depends on several interrelated factors, each of which is important in evaluating the others. As far as possible, these factors should be considered carefully *before* applying for a patent. Thus, it is necessary to determine what the invention is before it can be described and claimed. Such a determination will require considering the prior art known to the inventor or established by a search conducted on the matter in question. Such prior art should be evaluated to determine what problems or limitations it presents, and how the inventor intends to avoid such problems or obtain a result which cannot be achieved by the prior art. Finally, the matter in question should be scrutinized carefully by the inventor and his attorney to determine what is actually essential or critical to the invention, and what may be eliminated or replaced by equivalent components. Armed with such information, the true invention can be determined, and then described and claimed in the patent in such a manner as to emphasize the essential characteristics of the invention which distinguish it from the prior art, while excluding that which has been done before or is not essential. In this manner, the inventor and his attorney can cooperate to obtain the broadest and best patent protection possible under a given set of circumstances.

Notes About Inventions and Inventors

Contributed by
Patent Section
Detroit Office

THE following is a general listing of patents granted in the names of General Motors employes during the period April 1 through June 30, 1961.

AC Spark Plug Division
Flint, Michigan

• **James A. Norton,** (*associate in science degree, Flint Junior College, 1934; S.B. degree, 1936; and Ph.D. degree in organic chemistry, 1939; University of Chicago*) research scientist, inventor in patent 2,977,925 for an apparatus for measuring the time amount of radioactive material deposited on articles.

• **John A. McDougal,** (*B.S.M.E., Cornell University, 1943*) assistant chief engineer, and Jesse E. Eshbaugh, retired, inventors in patent 2,979,172 for a throttle control mechanism.

• **Joseph Zubaty,** (*M.S.M.E., University of Prague, 1918*) staff engineer—special assignment, inventor in patent 2,983,153 for a fluid pump control mechanism.

• **Virgil L. Helgeson,** (*B.E.E., University of Minnesota, 1948; M.S.E.E., Washington University, 1950*) senior engineer, and **Edward J. Loper,** (*B.S., Applied Mathematics and Mechanics, University of Wisconsin, 1954*) head, Systems Analysis, AC-Milwaukee, inventors in patents 2,985,365 for a solution possible indicator for bombing computer; 2,985,373 for an obstacle clearance computer system for aircraft; 2,988,816 for an altimeter ranging; and 2,988,960 for a bombing navigational computer.

• **F. Robert J. Fowler,** (*B.M.E., General Motors Institute, 1954; M.S.E., University of Michigan, 1961*) project engineer, inventor in patent 2,987,887 for a hydraulic coupling with fluid content control.

• **Gordon W. Harry,** (*B.S.M.E., University of Michigan, 1923*) staff engineer, and **Earl W. Pierce,** (*B.S.M.E., University of Michigan, 1939*) senior project engineer, inventors in patent 2,988,102 for a moisture blow off-valve.

• **Robert W. Smith,** (*Ph.D., physics, University of Michigan, 1933*) staff scientist, inventor in patent 2,988,662 for a spark plug with improved auxiliary spark gap.

• **Gustav F. Rademacher,** (*B.S., Michigan State University, 1941*) project engineer, inventor in patent 2,988,663 for a spark plug.

• **Homer D. Boggs**, (*B.S.M.E., University of Michigan, 1933*) research metallurgist, inventor in patent 2,988,807 for a method of aluminizing cobalt base alloys and article resulting therefrom.

• **Werner F. Schultz**, (*B.E.E., University of Detroit, 1938*) development engineer and Jesse E. Eshbaugh*, inventors in patent 2,988,910 for a locking cap for a filler pipe.

• **Werner F. Schultz***, inventor in patent 2,989,644 for safety systems for electric fuel pumps.

Allison Division
Indianapolis, Indiana

• **Harvey W. Welsh**, (*B.S.M.E., Wayne State University, 1942; M.S.M.E., Columbia University, 1948*) chief, advanced projects, inventor in patents 2,968,468 and 2,971,743 for a sheet metal compressor casing and an interlocked blade shrouding, respectively.

• **Richard A. Hirsch**, (*University of Dayton and Sinclair College*) engineering group head, and **Lawrence McNamara**, (*B.S.M.E., Tri-State College, 1948*) senior project engineer, inventors in patent 2,969,685 for a control mechanism for variable pitch propellers.

• **Kenneth B. Harmon**, (*B.M.E., General Motors Institute, 1956*) project engineer, and **Robert M. Tuck**, (*B.M.E., General Motors Institute, 1947*) chief development engineer, inventors in patent 2,969,694 for a transmission.

• **Ulysses A. Breting**, senior reliability engineer; **Howard W. Christenson**, (*B.S., Oregon State University, 1938*) chief engineer, Research; and **Mark E. Fisher**, (*B.S.M.E., Purdue University, 1947*) senior project engineer, inventors in patent 2,969,695 for a transmission.

***Inventors' names marked with an asterisk have biographical listings noted previously in this issue's Notes About Inventions and Inventors.**

• **Dean K. Hanink**, (*B.S.Met.E., University of Michigan, 1942*) chief metallurgist, inventor in patent 2,970,091 for a method of alloying aluminum and copper.

• **Howard M. Geyer**, (*B.S.I.E., University of Alabama, 1940*) advanced systems engineer, inventor in patents 2,967,511 for a pneumatic actuator; 2,970,573 for an actuator with stroke end locks; 2,970,574 for a dual piston hydraulic centering actuator; 2,971,496 for a fluid pressure actuator and cooling means therefor; and 2,979,034 for a hydraulic actuator with load proportional locking means.

• **Robert G. Larkin**, (*B.S.M.E., Rose Polytechnic Institute, 1944*) senior project engineer; **Victor W. Peterson**, (*B.S.M.E., Rose Polytechnic Institute, 1939*) engineering supervisor; and Herbert N. Schnepel, retired, inventors in patent 2,971,613 for a propeller brake.

• **Dean K. Hanink***, and **Albert J. Shouldy, Jr.**, now with GM Research Laboratories, inventors in patent 2,971,899 for a method of electroplating aluminum.

• **Ward A. Bunker**, (*Anderson Trade School, Sinclair College*) senior project engineer; **James R. May**, (*B.S.M.E., Purdue University, 1941*) assistant chief engineer, Accessories; and Stephen A. Denman, no longer with GM, inventors in patent 2,972,390 for a vehicle road speed control.

• **Hamilton L. McCormick**, (*E.E. and M.E. degrees, Johns Hopkins University, 1922, 1924*) on special assignment, inventor in patent 2,972,470 for turbine construction.

• **William F. Egbert**, (*B.S.Aero.E., Tri-State College, 1941*) chief engineer, Rocket Engine Cases, and **Theodore O. Wiese**, (*University of Wisconsin Extension*) layout man, inventors in patent 2,974,477 for a variable jet nozzle and shroud.

• **Vernon M. Zwicker**, (*B.S.M.E., University of Illinois, 1939*) senior project engineer, inventor in patent 2,975,007 for a self-aligning bearing mounting.

• **Ward A. Bunker***, and Stephen A. Denman*, inventors in patent 2,976,946 for hydraulic road speed control.

• **Fred C. Flowers**, (*B.S. in chemistry, Purdue University, 1950*) experimental chemist, inventor in patent 2,977,248 for a basket and method of making same.

• **Robert J. Wente**, (*B.S.M.E., Purdue University, 1941*) head, advanced design power turbine controls, inventor in patent 2,978,034 for a turboprop engine idling control.

• **John A. Clements**, (*B.S.M.E., Iowa State College, 1952*) senior experimental engineer, and **Leslie Stallwood**, (*B.S.M.E., Purdue University, 1942*) general foreman, inventors in patent 2,978,056 for an automatic steering device.

• **Kent L. Hahn**, (*B.S.M.E., Purdue University, 1949*) group senior project engineer, inventor in patent 2,978,166 for a compressor bleed control.

• **Mark E. Fisher**, (*B.S.M.E., Purdue University, 1947*) senior project engineer, and **Robert M. Tuck***, inventors in patent 2,978,928 and 2,987,940 both for a transmission.

• **William G. Livezey**, (*International Correspondence School*) analytical engineer, inventor in patent 2,981,103 for a torque applying device.

• **William F. Egbert***, inventor in patent 2,982,980 for an afterburner nozzle.

• **Eugene J. Bevers**, (*B.S.M.E., University of Wisconsin, 1945*) group senior project engineer, and **Robert J. Wente***, inventors in patent 2,982,096 for a torque limiter.

• **Albert L. Hunt, Jr.**, (*B.S.M.E., Purdue University, 1951*) project engineer, inventor in patent 2,982,518 for a blade lock pin retainer.

• **Warren G. Perin**, (*General Motors Institute*) senior project engineer, and **Victor W. Peterson**, (*B.S.M.E., Rose Polytechnic Institute, 1939*) engineer, inventors in patent 2,983,029 for an antifriction bearing.

• **Arthur W. Gaubatz**, (*B.S., University of Wisconsin, 1920*) senior project engineer, inventor in patent 2,983,530 for a shaft seal.

• **Russell D. Tyler,** (*B.S.E.E., Rose Polytechnical Institute, 1947; B.S. Bus. Adm., Butler University, 1955*) superintendent, controls and instrumentation development, and **John M. Whitmore,** (*B.E.E., The Ohio State University, 1936*) chief test engineer, inventors in patent 2,985,243 for a torque-actuated engine control.

• **John D. Moeller,** (*B.S.A.E., B.N.S., Purdue University, 1949*) senior project engineer, and Ted R. Scarff and Gerald M. Sturm, no longer with GM, inventors in patent 2,986,094 for a gas driven hydraulic pump.

• **Roy C. Bodem,** (*University of Dayton*) designer; **Roy H. Brandes,** senior experimental engineer; **Richard A. Hirsch***; and Edward H. McDonald and Carl F. Wood, no longer with GM, inventors in patent 2,986,220 for a variable pitch propeller assembly for multi-power plant aircraft.

Buick Motor Division
Flint, Michigan

• **Rudolph J. Gorsky,** (*General Motors Institute, 1935*) staff engineer, inventor in patent 2,977,821 for a transmission.

• **Vernon W. Dakin,** (*General Motors Institute*) senior process engineer, inventor in patent 2,982,067 for a packaging machine.

• **Leonard M. Morrish,** (*Michigan State University*) staff engineer, and **Lloyd E. Muller,** (*B.S.M.E., University of Kansas, 1929*) director, Experimental Engineering, inventors in patent 2,985,252 for an exhaust muffler.

• **Henry W. Boylan,** (*Wayne State University, 1929*) staff engineer, inventor in patent 2,987,981 for an adjustable grille.

• **Eric R. Dietrich,** senior project engineer, inventor in patent 2,988,353 for a pneumatic spring construction.

• **Lindbergh C. Vogt,** (*B.S.E.E., Michigan State University, 1950*) senior contact engineer, inventor in patent 2,989,646 for electrical control circuits applicable to vehicle heating and air conditioning.

Chevrolet Motor Division
Warren, Michigan

• **Irwin K. Weiss,** (*B.S.M.E., Massachusetts Institute of Technology, 1939*) assistant staff engineer; **Alex C. Mair,** (*General Motors Institute*) staff engineer; **Charles W. Jackman,** (*International Correspondence School*) assistant staff engineer; **Arthur S. Brown,** (*B.S.M.E., University of Illinois, 1939*) experimental engineer; and **Garth R. Sayers,** (*B.S., Hillsdale College, 1942; B.I.E., General Motors Institute, 1950*) project engineer, inventors in patent 2,978,253 for an independent front wheel suspension caster and camber adjusting means.

• **Joseph F. Bertsch,** (*B.S.M.E., University of Cincinnati, 1948*) design engineer, and **Kai H. Hansen,** (*Lawrence Institute of Technology*) staff engineer, inventors in patents 2,978,256 for a dual height suspension control system and 2,983,506 for a fluid distribution system and apparatus therefor.

• **Robert W. Graham,** (*B.S.M.E., University of Michigan, 1949*) experimental engineer, inventor in patent 2,978,586 for a rotational indicator.

• **Frank C. Burrell,** (*B.S.M.E., University of Wisconsin, 1938*) research engineer, inventor in patent 2,981,379 for an automatic vehicle brake adjuster.

• **John G. Else,** (*B.S.E.E., University of Notre Dame, 1940*) assistant staff engineer, inventor in patent 2,981,480 for a heat control valve.

• **Gary W. Bergin,** (*B.M.E., General Motors Institute, 1957*) senior layout man, inventor in patent 2,982,576 for a vehicle.

• **Eugene B. Etchells,** (*B.S.E.E., University of Michigan, 1932*) assistant staff engineer; **Harry F. Barr,** (*B.M.E., University of Detroit, 1929*) chief engineer; and Adelbert E. Kolbe, retired, inventors in patents 2,983,335 and 2,988,081, both for an engine lubricating system.

• **James O. Brafford,** (*The Ohio State University*) experimental engineer, inventor in patent 2,983,911 for an engine speed warning system.

• **Phillip C. Bowser,** (*B.M.E., The Ohio State University*) now director, Research and Development, Buick Motor Division, inventor in patent 2,985,445 for a pneumatic spring control device.

• **Anthony Waydak,** design engineer, inventor in patent 2,988,068 for an engine cooling system.

• **Kai H. Hansen***, inventor in patent 2,988,162 for a motor vehicle.

Delco Appliance Division
Rochester, New York

• **Raymond H. Hara,** senior special tester, inventor in patent 2,979,126 for a flame pulsation suppressor for inshot gas burners.

• **Eugene R. Zeigler,** (*University of Rochester*) special development engineer, inventor in patent 2,979,751 for a windshield cleaning system.

• **Milton E. Simmons,** (*B.S.E.E. Rensselaer Polytechnic Institute, 1950*) project engineer; **Carl F. Finsterwalder,** (*B.S.E.E., Clarkson College, 1928*) design engineer; and **Frank J. Terkoski,** (*B.S.E.E., Pennsylvania State University, 1950*) project engineer, inventors in patent 2,982,873 for a dynamo electric machine.

• **Laszlo Z. Pokorny,** (*M.S., Royal Hungarian Technical University, Budapest, 1939*) project engineer, inventor in patent 2,983,157 for a variable diameter pulley.

• **Francis M. Ryck,** (*B.S., University of Rochester, 1950*) assistant supervisor, windshield wiper applications, inventor in patent 2,983,532 for a windshield wiper arm to shaft attachment.

• **Peter R. Contant,** (*University of Rochester*) senior project engineer; **Loren R. Gute,** (*B.S.E.E., Michigan State University, 1940*) supervisor of defense products; **Elmer E. Reese,** (*B.S.M.E., Lehigh University, 1952*) project engineer; **Robert M. Fox,** (*B.M.E., General Motors Institute, 1950*) senior project engineer, Fisher Body Division; **Delbert D. DeRees,** (*B.M.E., General Motors Institute, 1958*) layout draftsman, Fisher Body Division; and Harry W. Schmitz, not with GM, inventors in patent 2,985,024 for a windshield cleaning mechanism.

• **William E. Fritz,** (*Technical College of Thurengia, Hildburghausen, Germany, 1928*) senior development engineer, inventor in patent 2,985,778 for a synchronous motor.

• **Richard C. Stiles,** electrical laboratory technician, inventor in patent 2,985,782 for a current collector contact means.

• **John G. Hart,** (*B.S.M.E., University of Rochester, 1949*) assistant master mechanic, inventor in patent 2,985,904 for windshield wiper blade assemblies.

Delco Moraine Division
Dayton, Ohio

• **Don R. Osborn, Jr.,** (*General Motors Institute*) chief designer, and **Richard A. Rogers,** (*Denison University*) designer, inventors in patent 2,983,136 for an air gage.

• **Frederick W. Sampson,** (*M.E., Cornell University, 1924*) section engineer on special assignment, inventor in patent 2,987,-145 for a brake structure.

Delco Products Division
Dayton, Ohio

• **John S. Wolfe,** (*B.A., The Ohio State University, 1934*) chemist, inventor in patent 2,980,475 for a lubricant system.

• **George A. Neyhouse,** (*E.E., Rose Polytechnic Institute, 1939*) project engineer; **Jack W. Savage,** (*B.S.E.E., University of Toledo, 1950*) project engineer; and **Ralph K. Shewmon,** (*General Motors Institute, 1934*) assistant chief engineer, inventors in patents 2,981,089 for a power drive apparatus and 2,989,654 for a multi-speed dynamoelectric machine.

• **Harold E. Schultze,** project engineer, inventor in patent 2,984,321 for a hydraulic shock absorber with compression cutoff.

• **Paul B. Greene,** senior designer; **Albert B. Mewhinney,** (*B.S.E.E., Rose Polytechnic Institute, 1936*) superintendent, Tool Design and Machine Development; and **Francis E. Wirtz,** senior process engineer, inventors in patent 2,988,291 for a stator coil winding machine.

• **Irving M. Levy,** (*B.S.E.E., Washington University, 1927*) staff engineer; **Jack W. Savage***; and **Raymond A. Flora,** designer, inventors in patent 2,990,112 for a ventilating means.

Delco Radio Division
Kokomo, Indiana

• **James H. Guyton,** (*B.S.E.E., 1934, and M.S.E.E., 1935, Washington University*) chief engineer—radio; **Richard L. Jenkins,** (*B.S.E.E., Purdue University, 1944*) staff engineer; **Clarence J. Votava,** (*B.S.E.E., Illinois Institute of Technology, 1943*) projects supervisor; and David W. Dodge, no longer with GM, inventors in patent 2,981,836 for a transistor favorite station signal seeking tuned radio.

• **Max J. Manahan,** (*B.S.E.E., Milwaukee School of Engineering, 1922*) staff engineer, and **Kenneth S. Vogt,** (*The Ohio State University*) senior project engineer, inventors in patent 2,981,870 for a high frequency relay control circuit.

• **James H. Guyton***, and Leslie E. Scott, no longer with GM, inventors in patent 2,983,815 for an automatic gain control.

• **Max J. Manahan***, inventor in patent 2,989,688 for a saturation permeability tuned transistor radio.

Detroit Transmission Division
Ypsilanti, Michigan

• **Darrell R. Sand,** (*B.M.E., General Motors Institute, 1949*) assistant staff engineer, inventor in patent 2,977,766 for a de-sludging device.

• **Walter B. Herndon,** (*B.S.E., State College of Washington, 1928, and M.S.E., University of Michigan, 1930*) director of reliability, and Victor C. Moore, no longer with GM, inventors in patent 2,983,164 for accessory drive transmissions.

• **Jack W. Qualman,** (*General Motors Institute, 1937*) assistant chief engineer, and Victor C. Moore*, inventors in patents 2,983,165 for a dual range transmission and 2,987,941 for a transmission.

Electro-Motive Division
La Grange, Illinois

• **Thomas B. Dilworth,** chief engineer, inventor in patent 2,977,762 for a hydraulic governor pressure control mechanism.

• **Elmer E. Thiessen,** (*B.S.E.E., Iowa State College, 1940*) a-c electrical design engineer, inventor in patent 2,979,432 for an insulating method.

• **Willard R. Stigler,** senior project engineer, and **Walter Drabik,** senior designer, inventors in patent 2,990,487 for a method and wedges for conducting heat from slots of dynamoelectric machine.

GM Engineering Staff
Warren, Michigan

• **Johannes Rosenkrands,** (*M.S.M.E., Royal Technical University of Denmark, 1946*) assistant engineer in charge, Structure and Suspension Development Group, inventor in patent 2,978,255 for an independent front wheel suspension, and in patents 2,981,353 and 2,989,321, both for a swing axle rear suspension.

• **Andries C. deWilde,** (*M.M.E., 1928 and M.E.E., 1931, Technical University of Delft, Holland*) senior project engineer, and **William K. Steinhagen,** (*B.S.E., 1947, M.S.E., 1948, University of Michigan*) assistant engineer in charge, Power Development Group, inventors in patent 2,979,643 for a solenoid valve assembly.

• **Oliver K. Kelley,** (*B.S., Chicago Technical College, 1925 and Massachusetts Institute of Technology*) now director, Military Vehicular Systems, Defense Systems Division, inventor in patents 2,981,122 for accessory drives; 2,981,124 for a four phase converter drive, and 2,981,126 for a power shifting multi-step transmission.

• **George M. Vanator,** (*B.S., 1939, and M.S., 1941, The Ohio State University*) assistant department head, Noise and Vibration Laboratory, GM Proving Ground, inventor in patent 2,983,141 for a gear inspection apparatus.

• **Gilbert K. Hause,** engineer in charge, Transmission Development Group, inventor in patent 2,983,160 for a transmission selector control.

• **Darl F. Caris,** (*B.S.E.E., 1926, and professional degree of E.E., 1932, University of Michigan*) engineer in charge, Power Development Group, and **Boris J. Mitchell,** (*B.S.M.E., Detroit Institute of Tech-*

nology, 1940) assistant engineer in charge, Engine Development Section, Power Development Group, inventors in patent 2,983,554 for an engine bearing assembly and method of making the same.

• **Chi Mou Tsang,** (*B.S.M.E., Purdue University, 1940; M.S., 1942 and Ph.D., 1944, University of Michigan*), senior project engineer, inventor in patent 2,983,565 for a piston.

• **Darl F. Caris***, inventor in patent 2,985,148 for an engine.

• **Lothrop M. Forbush,** (*B.S., Harvard University, 1939, and Massachusetts Institute of Technology*) engineer in charge, Vehicle Development Group; **John M. Winston,** (*U.S. Naval Academy and B.S.E.E., A & M College of Texas, 1938*) senior design engineer; **Walter H. Zimmerman,** (*B.S.M.E., University of Michigan 1941*) design leader; and Roland V. Hutchinson, retired, inventors in patent 2,986,237 for a drive shaft power actuator for hydraulic brakes.

• **Clifford C. Wrigley,** (*B.S.M.E., University of Colorado, 1936 and Yale University*) assistant engineer in charge, Transmission Development Group, inventor in patent 2,987,346 for a front and rear braking force regulating mechanism.

• **William H. Kolbe,** (*B.S.M.E., University of Michigan, 1950*) section engineer, and **Alexander J. Sagady,** (*B.S.M.E., Detroit Institute of Technology, 1945*) senior design engineer, inventors in patent 2,988,345 for an air valve carburetor.

• **John S. Wroby,** (*B.M.E., University of Detroit, 1942*) design engineer, inventor in patent 2,989,330 for a resilient suspension means.

Euclid Division
Hudson, Ohio

• **Anton Z. Panasewicz,** (*Fenn College, 1951*) designer, inventor in patent 2,977,-817 for a variable ratio lever mechanism.

• **Ralph J. Bernotas,** (*B.S.M.E., and M.S.M.E., Case Institute of Technology*) senior product engineer, inventor in patents 2,978,124 and 2,981,356 for a cradle loader and a power steering follow-up control, respectively.

• **Janis Mazzarins,** (*Technical University, Aachen, West Germany*) senior designer, inventor in patent 2,988,926 for a master link.

Fisher Body Division
Warren, Michigan

• **Napoleon P. Boretti,** (*B.E.E., University of Detroit, 1935*) assistant engineer in charge, Process Development Department; **Arthur F. Hessler,** senior production engineer; and **Thomas W. Shearer, Jr.,** (*B.S.E.E., Lawrence Institute of Technology, 1943*) supervisor, Process Development Department, inventors in patent 2,978,569 for a method and apparatus for forming holes in sheet metal.

• **Victor H. Dutchik,** (*Washington University*) assistant engineer in charge, body engineering, inventor in patent 2,981,387 for a clip.

• **James D. Leslie,** (*B.M.E., University of Detroit, 1939*) engineer in charge, Mechanical Department, inventor in patent 2,981,561 for a self-closing lock striker.

• **Louis P. Garvey,** (*B.M.E., University of Detroit, 1940*) assistant engineer in charge, Product Engineering Activity, inventor in patent 2,982,335 for a seat positioning mechanism.

• **Ralph M. Stallard,** (*B.S.E.E., Michigan College of Mining and Technology, 1949*) senior production engineer, and Ming C. Hsu, no longer with GM, inventors in patent 2,982,456 for a method for cutting thermoplastic materials.

• **Algin O. Richardson,** pipefitter, Kansas City plant, inventor in patent 2,982,479 for solder spray gun improvements.

• **Louis P. Garvey***, and **Clyde H. Schamel,** (*B.S.E.E., University of Notre Dame, 1927*) senior engineer in charge, Experimental and Development Department, inventors in patent 2,983,545 for vehicle seat positioning apparatus.

• **Stanley D. Cockburn,** (*Lawrence Institute of Technology*) senior designer, and **James D. Leslie***, inventors in patent 2,987,907 for an integral latch.

• **Bruce E. Kevelin,** (*B.M.E., General Motors Institute, 1958*) production engineer; **Ted A. Redo,** (*General Motors Institute*) supervisor Tool Design Department; and **J. Woodrow Willett,** (*B.E.E., Universersity of Detroit, 1950*) senior production engineer, inventors in patent 2,988,129 for a machine and method for dielectrically embossing trim strip material.

• **Robert M. Fox,** (*B.M.E., General Motors Institute, 1950*) senior project engineer, inventor in patent 2,989,333 for an adjustable means for a door latch operator.

Frigidaire Division
Dayton, Ohio

• **Byron L. Brucken,** (*B.S., University of Dayton, 1956*) senior project engineer, and **George B. Long,** (*B.S.E.E., Purdue University, 1937*) supervisor, Future Products Engineering, inventors in patent 2,978,190 for a garbage grinder.

• **John H. Heidorn,** (*General Motors Institute*) senior project engineer, inventor in patent 2,978,879 for a refrigerating apparatus.

• **John T. DeWitte,** (*M.S. in physics, The Ohio State University, 1936*) senior project engineer, and **Clifford H. Wurtz,** (*B.S., University of Illinois, 1929*) manager, Refrigerated Appliances Engineering, inventors in patent 2,979,922 for a refrigerating apparatus.

• **James W. Jacobs,** (*B.S.M.E., University of Dayton, 1954*) manager, Research and Future Products Engineering, inventor in patent 2,980,120 for a variable spray device for dishwasher.

• **James W. Jacobs***, and **Kenneth A. Harnish,** (*B.S.Arch. E., University of Michigan, 1923*) senior layout man, inventors in patent 2,980,480 for a domestic appliance.

• **Richard S. Gaugler,** (*B.S.Ch.E., Purdue University, 1922*) supervisor of major product line; **Earl S. Schlotterbeck,** (*B.S.M.E., Purdue University, 1948*) senior project engineer; and **Raymond F. Schultz,** (*B.S.C.E., University of Cincinnati, 1932*)

supervisor, Auto Air Conditioning Application, inventors in patent 2,981,076 for a refrigerating apparatus.

• **James L. Miller,** (*B.S.M.E., University of Cincinnati, 1950*) senior project engineer, inventor in patent 2,981,083 for an air conditioner.

• **Joseph R. Pichler,** (*B.I.E., The Ohio State University, 1934*) section head, Refrigerated Appliances Engineering Department, inventor in patent 2,982,113 for an ice making apparatus.

• **Clifford H. Wurtz***; **Leonard J. Mann,** (*M.E., University of Cincinnati, 1940*) senior project engineer; and John C. Miller, no longer with GM, inventors in patent 2,982,115 for a refrigerating apparatus.

• **Mervin R. Butts,** (*Associate Degree, M.E., University of Dayton, 1958*) contact engineer, inventor in patent 2,986,017 for a refrigerating apparatus.

• **Byron L. Brucken***, inventor in patent 2,986,914 for a laundry appliance.

• **Kenneth O. Sisson,** (*B.S.M.E., South Dakota State College, 1936*) senior project engineer, inventor in patent 2,987,904 for a domestic appliance.

• **Justus Miller,** (*B.S.M.E., Tri-State College, 1948*) senior project engineer, inventor in patent 2,987,984 for a room air conditioner.

• **Thomas H. Fogt,** project engineer, inventor in patent 2,988,263 for a refrigerating apparatus.

• **George B. Long***, inventor in patent 2,988,432 for an odor destroyer.

• **Richard E. Gould,** (*B.S.M.E., 1923, and M.S.M.E., 1927, University of Illinois*) chief engineer, inventor in patent 2,989,854 for a vehicle refrigeration.

• **Lester M. Miller,** (*Dayton Art Institute, Art Academy of Cincinnati, and the Central Academy of Commercial Art*) junior engineer, inventor in patent 2,990,062 for a refrigerating apparatus.

• **Richard E. Thompson,** (*B.S.M.E., University of Cincinnati, 1949*) senior project engineer, inventor in patent 2,989,855 for a refrigerating apparatus.

GMC Truck and Coach Division
Pontiac, Michigan

• **Ralph H. Bertsche,** (*Colorado School of Mines*) head, Electrical Department, and **Eldred E. Gegenheimer,** (*B.M.E., General Motors Institute, 1950*) laboratory supervisor, inventors in patent 2,987,637 for a dynamoelectric machine.

• **Theron E. Neir,** (*B.M.E., Lawrence Institute of Technology, 1942*) drafting supervisor, inventor in patent 2,988,071 for a concentric valve internal combustion engine.

Guide Lamp Division
Anderson, Indiana

• **David P. Clayton,** designer, inventor in patent 2,979,687 for a lamp socket.

Harrison Radiator Division
Lockport, New York

• **Frank A. Disinger,** senior product designer, and **Vincenzo A. Nicolia,** (*B.S.M.E., George Washington University, 1952*) engineer in charge, Nuclear Heat Transfer Equipment Section, inventors in patent 2,988,335 for heat exchangers.

Inland Manufacturing Division
Dayton, Ohio

• **Edward P. Harris,** (*M.E., Cornell University, 1931*) section engineer, and **James R. Wall,** (*B.Ch.E., University of Dayton, 1937 and M.Ch.E., Cornell University, 1939*) section head, Advanced Development Laboratory, inventors in patent 2,980,167 for a seat construction.

GM Manufacturing Staff
Warren, Michigan

• **Kenneth Secunda,** (*B.S.M.E., Wayne State University, 1950*) senior engineer, inventor in patent 2,978,101 for a hardness testing device.

• **Harry J. Gilliland,** (*B.S.Met. E., Missouri School of Mines, 1947*) supervising metallurgical engineer, and **Donald W. Jones,** (*Michigan State University*) designer, inventors in patent 2,982,480 for a metal spray gun.

• **Richard N. Graeber,** (*B.E.E., Cornell University, 1953*) now supervisor, Gyro Process Control, AC Spark Plug Division, Milwaukee plant, and **Glen E. Wanttaja,** (*B.S.E.E., Michigan College of Mining and Technology, 1950 and M.S.E.E., Wayne State University, 1956*) now with AC Spark Plug Division, Milwaukee plant, inventors in patent 2,977,843 for an apparatus for aiming lamps.

New Departure Division
Bristol, Connecticut

• **Bryce T. Ruley,** (*B.S., 1936; M.A., 1942; Yale University*) manager, Applied Mathematics, inventor in patent 2,975,-008 for a separator.

• **William Blinder,** (*B.S.M.E., University of Connecticut, 1947; and Masters in Management Engineering, Rensselaer Polytechnic Institute, 1960*) senior research and development engineer, inventor in patents 2,983,557 and 2,983,559, both for an antifriction bearing.

GM Overseas Operations Division
New York, New York

• **Alfred Doerper,** (*engineering degree, Technical University, Aachen, Germany, 1924*) superintendent of experimental shop, Product Engineering Department, Adam Opel, A.G., Russelsheim/Main, Germany, inventor in patent 2,981,390 for a transmission clutch shift facilitation device.

• **Bruno Ewert,** (*engineering degree, Staatstechnikum, Strelitz/Mecklenburg, Germany, 1937*) senior designer and group leader, Adam Opel, A.G., Russelsheim/Main, Germany, inventor in patent 2,983,328 for a motor vehicle suspension.

Packard Electric Division
Warren, Ohio

• **Robert E. Kirk,** (*Case Institute of Technology*) product designer, inventor in patent 2,982,939 for a socket and locking means.

• **Joseph H. Hopkins,** (*B.S. in engineering, Brown University, 1926*) product engineer, and **Allan S. Van Slyke,** project engineer, inventors in patent 2,989,723 for a terminal means.

• **Robert C. Woofter,** (*Fenn College*) chief, Wiring Assemblies Design and Development Section, inventor in patent 2,989,724 for an electrical connector.

Pontiac Motor Division
Pontiac, Michigan

• **Clayton B. Leach,** (*A.B. in mathematics and chemistry, Park College, 1934, and General Motors Institute*) chassis engineer, and **Lester V. Ostrander,** assistant chassis engineer, inventors in patent 2,979,357 for a bumper-conduit exhaust assembly.

• **Fred F. Timpner,** (*B.S.M.E., Louisiana State University, 1943, and M.S., Chrysler Institute of Engineering, 1948*) assistant advance design engineer; **John Z. DeLorean,** (*B.S.I.E., Lawrence Institute of Technology, 1948; M.S.A.E., Chrysler Institute, 1952; M.B.A., University of Michigan, 1957; and Detroit College of Law*) assistant chief engineer in charge of advanced design and body; and **Carl J. Miller,** chief draftsman, Advance Design, inventors in patent 2,980,441 for a fluid suspension unit.

• **Dimitry B. Sergay,** (*B.S.M.E., Wayne State University, 1947*) senior designer, inventor in patent 2,981,023 for a sealing of revolver firing chamber.

• **Robert H. Knickerbocker,** (*B.M.E., University of Detroit, 1951*) senior project engineer, and **Harry L. Redding,** design group leader, inventors in patent 2,981,-351 for an exhaust system support.

• **Albert E. Roller,** (*M.E., College for Mechanical Engineers, Esslinger, Germany, 1937*) assistant advanced design engineer, inventor in patent 2,981,354 for a pneumatic vehicle suspension with torque responsive pitch control.

• **Lewis E. Herr,** (*B.S., Pennsylvania State College, 1952*) senior designer, inventor in patent 2,988,161 for a suspension control arm construction.

GM Research Laboratories
Warren, Michigan

• **Eric W. Weinman,** (*B.S.Chem.E., 1938; M.S.Met.E., 1958, Wayne State University*) senior metallurgical engineer, inventor in patent 2,977,673 for a method of forming composite metal bearings.

• **Ronald T. Bundorf,** (*B.S.M.E., University of Pittsburgh, 1955 and M.S.M.E., Wayne State University, 1961*) research engineer, inventor in patent 2,978,254 for an interconnected fluid suspension system.

• **William B. Larson,** (*B.S.Met.E., Michigan State University, 1953*) superintendent, Research and Development, Central Foundry Division; **Robert F. Thomson,** (*B.S.M.E., 1937; M.S.M.E., 1940; and Ph.D., 1941, University of Michigan*) head, Metallurgical Engineering Department; and **Fred J. Webbere,** (*B.S.Met.E., University of Wisconsin, 1941*) supervisor, Metallurgical Engineering Department, inventors in patent 2,978,320 for a method for producing a high strength ferrous metal.

• **Joseph B. Bidwell,** (*B.S.M.E., Brown University, 1942*) head, Engineering Mechanics Department, inventor in patent 2,979,148 for a vehicle steering system with oscillation damping.

• **Alexander Somerville,** (*B.S.E.E., 1943; M.S.E.E., 1947; and Ph.D., 1950, Northwestern University*) supervisor, Isotope Laboratory, inventor in patent 2,979,617 for a scintillation detector circuit.

• **John M. Farrell,** (*Lawrence Institute of Technology*) project engineer, and Edward J. Martin, retired, inventors in patent 2,979,647 for a switch circuit and actuating mechanism.

• **Sanford R. Black,** (*Detroit College of Applied Science*) senior layout man, inventor in patent 2,980,992 for a balancing apparatus.

• **Joseph F. Lash,** (*B.S.M.E., Michigan State University, 1938*) supervisor, Electro-Mechanics Department, inventor in patent 2,981,112 for an unbalance measuring apparatus.

• **Worth H. Percival,** (*B.S.M.E., Iowa State College, 1942, and M.S.M.E., Massachusetts Institute of Technology, 1947*) assistant head, Mechanical Development Department, inventor in patent 2,983,267 for an accumulator supercharging.

These patent listings are informative only and are not intended to define the coverage which is determined by the claims of each one.

• **Robert F. Falberg,** (*B.S.M.E., Michigan College of Mining and Technology, 1948*) senior research engineer, inventor in patents 2,985,378 and 2,988,873 for an accumulator type injection apparatus and free piston engine, respectively.

• **Philip K. Trimble,** (*B.S.E.E., University of Illinois, 1952*) senior research engineer, inventor in patent 2,985,833 for a balancing apparatus.

• **Robert Schilling,** (*M.E. degree, Technical University, Munich, Germany, 1922*) now special assistant to the chief engineer, Adam Opel A.G., Russelsheim, Main, Germany; **George W. Jackson,** (*B.S.M.E., Purdue University, 1937*) assistant chief engineer, Delco Products Division; and Robert E. Owen, no longer with GM, inventors in patent 2,987,311 for a ride height control system.

• **William F. King,** (*General Motors Institute, 1940 and B.S.M.E., University of Michigan, 1941*) head, Electro-Mechanics Department, inventor in patent 2,988,918 for a balancing machine.

• **Archie D. McDuffie,** (*General Motors Institute, 1934*) now staff engineer, Buick Motor Division, inventor in patent 2,989,065 for a fuel control unit for an internal combustion engine.

Rochester Products Division
Rochester, New York

• **Bernard E. Frank,** (*civil engineering degree, Ecole Speciale D'Inginieur Technicien, Charleroi, Belgium, 1939*) superintendent, Manufacturing Development; **Gerard T. Ruflin,** (*B.S.M.E., Brown University, 1947*) engineer; **Robert F. Thomson,** (*B.S.M.E., 1937; M.S.M.E., 1940; and Ph.D., 1941, University of Michigan*) head of Metallurgical Engineering Department, GM Research Laboratories; and Isadore Caplan, not with GM, inventors in patent 2,982,-312 for tubing and method of making coated tubing.

• **Howard H. Dietrich,** (*B.S.E.E., Purdue University, 1926, and Yale University*) senior research and experimental engineer, and Frank B. Page, not with GM, inventors in patent 2,983,100 for a fuel control system for jet engines.

• **Richard J. Brunner**, (*Armour Institute, and University of Michigan Extension School*) senior experimental engineer, inventor in patent 2,985,196 for an anti-stall device.

• **Lawrence C. Dermond**, (*Purdue University and Tri-State College*) staff engineer, inventor in patent 2,988,342 for a fuel injection system.

Saginaw Steering Gear Division
Saginaw, Michigan

• **Donald P. Marquis**, (*B.S.Chem.E., 1934 and M.S., 1939, Wayne State University*) assistant chief engineer, inventor in patent 2,978,886 for a universal joint.

• **Earl W. Glover**, designer, inventor in patents 2,981,084 and 2,983,119, both for a universal joint.

• **Robert L. White**, (*B.S.M.E., Purdue University, 1947*) design engineer, inventor in patent 2,983,120 for a roller spline.

• **Robert D. Wight**, (*B.M.E., General Motors Institute, 1957*) project engineer, inventor in patent 2,984,997 for a universal joint.

• **Melvin A. Schultz**, designer, inventor in patent 2,985,030 for a transmission control.

• **Paul V. Wysong, Jr.**, (*University of Kansas*) chief applications engineer, inventor in patent 2,988,059 for a fluid power steering control valve.

GM Styling Staff
Warren, Michigan

• **Roger L. Crispell**, (*Pratt Institute*) chief designer, Industrial Design, and **William A. Hanifan**, (*Wayne State University*) senior project engineer, inventors in patent 2,978,567 for a domestic appliance.

• **Robert F. Smith**, (*General Motors Institute, 1930*) assistant engineer in charge, Product and Exhibit Design Studio, inventor in patent 2,978,999 for an incinerator with compacter.

• **Roger L. Crispell***, and **Clarence I. Vellner**, senior design engineer, inventors in patent 2,979,053 for a domestic appliance.

• **Peter W. Wozena**, (*Wayne State University*) creative designer, and Gordon R. Swanson, no longer with GM, inventors in patent 2,979,327 for a flush type vehicle window.

• **Ronald W. Roe**, (*B.S.M.E., Michigan State University, 1956*) research engineer, inventor in patent 2,981,537 for a self-dampening torsilastic suspension.

• **Louis Gelfand**, (*Wayne State University*) project engineer, inventor in patent 2,985,003 for a sonic washer.

• **James M. Helka**, senior layout man, inventor in patent 2,987,962 for a remotely controlled mirror.

• **Julius Hezler, Jr.**, senior design engineer, inventor in patents 2,987,979 for a roof ventilator for vehicles and 2,989,338 for a mounting and sealing means for vehicle windows.

Ternstedt Division
Detroit, Michigan

• **Joseph Konopka**, (*B.S.E.E., University of Detroit, 1951*) design group leader, inventor in patent 2,977,626 for a friction hinge.

• **Louis Weberman**, (*B.S.M.E., Lawrence Institute of Technology, 1953*) senior project engineer, inventor in patent 2,978,009 for a seat adjuster.

• **Alfonsas Arlauskas**, (*B.S.M.E., Bradford Technical College, England, 1953*) design group leader, inventor in patent 2,978,242 for a window regulator mechanism.

• **Arthur W. Hollar, Jr.**, (*B.S.M.E., University of Michigan, 1941*) senior designer, inventor in patent 2,980,945 for a door check and hold open.

• **Barthold F. Meyer**, (*B.S.M.E., Pratt Institute, 1939, and Johns Hopkins University*) engineering group supervisor, Product Engineering, inventor in patent 2,983,307 for a seat adjusting mechanism.

• **Alfonsas Arlauskas***, and **Arthur W. Hollar, Jr.***, inventors in patent 2,983,544 for a finishing molding for automobile bodies.

• **Bewley D. Priestman**, (*B.A. in engineering science, 1938 and M.A.M.E., 1942, University of Cambridge, England*) engineering group supervisor, Product Engineering, inventor in patent 2,985,477 for a control assembly for a vehicle door latch.

New Educational Aids Available to Educators

NEW MOTION PICTURE ON GM PROVING GROUNDS

A new 16-mm motion picture entitled "Cross Section of America" is now available for loan to educators at no charge, except that required for return postage. The film shows scenes of vehicle testing operations conducted by General Motors at its proving ground facilities in Michigan, Arizona, and Colorado. The types of tests shown range from routine mileage tests to dramatic shots of panic stops, J-turns, roll-overs, and crash tests. Also included is information on roadside design and traffic control for highway safety.

Running time is 22 minutes. Copies may be obtained by writing to General Motors Corporation, Public Relations Staff, Film Library, General Motors Building, Detroit 2, Michigan.

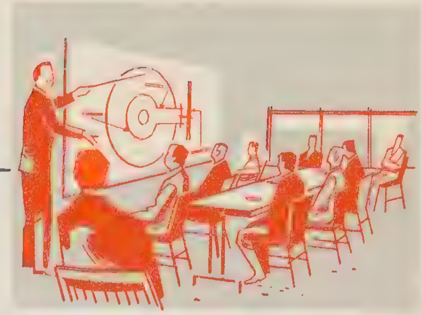
NEW GM BOOKLET ON GUIDANCE

A new booklet entitled "Can I Be A Draftsman?" is now available from General Motors. Written for student readership, the booklet describes several kinds of drafting jobs in fields such as engineering, automobile styling, patents, and architecture. It discusses the aptitudes and training that students should have and indicates some of the career opportunities offered in drafting.

This is another GM educational aid developed for use in connection with student guidance at the secondary school level. It is similar to other GM booklets in this area, namely, "Can I Be A Scientist Or Engineer?", "Can I Be A Craftsman?", "Can I Be A Technician?", "Can I Be An Office Worker?", and "Can I Get the Job?".

It is available to educators on a request basis at no charge. Write to the Educational Relations Section at the address given in the masthead of this issue.

Technical Presentations by GM Engineers and Scientists



Information about technical developments in General Motors is made available through several media, one of which is the technical presentation. Presentations, such as those listed below, include lectures to student engineering classes or societies, papers presented before professional groups, and talks before civic or governmental organizations. Educators who wish to arrange for GM engineers and scientists to speak to student groups may write to the Educational Relations Section, Public Relations Staff, General Motors Corporation, General Motors Technical Center, Warren, Michigan.

Automotive Engineering

Roger D. Wellington, assistant staff engineer, Detroit Diesel Engine Division, before the Alfred Society of Diesel Technicians, Hornell, New York, title: Detroit Diesel Series 71 Aluminum Engine Development.

William H. Jackson, superintendent, laboratories and shops, Harrison Radiator Division, before the Vocational Teachers Trade and Industrial Summer Workshop, Okmulgee, Oklahoma, title: Current Automotive Air Conditioning Systems and Service Problems Associated with Them.

Mieczykslaw G. Bekker, group head —land operations, Defense Systems Division, before the First International Conference on Mechanics of Soil-Vehicle Systems, St. Vincent, Italy, title: Evaluation and Selection of Optimum Vehicle Types under Random Terrain Conditions.

From Rochester Products Division: **Howard Gladding,** service manager, before the Automotive Boosters Club, Rochester, New York, title: Rochester Products Division and Carburetion; and **Nelson W. Seeber, Jr.,** regional service engineer, before the San Jacinto, Texas, Corvette Club, title: Carburetion and Fuel Injection.

From Allison Division: **M. D. McCuen,** project administration engineer, before the Downtown Sertoma Club, Indianapolis, title: Pistons or Pinwheels—Will Your Car Have a Gas Turbine Engine Soon?; and **J. M. Wetzler,** project manager, small gas turbine engines, before the Detroit sections, A.S.M.E. and Institute of Aero-Space Sciences, title: The GMT-305 Engine and the Requirements for an Automotive Gas Turbine.

From Chevrolet Motor Division: **Zora Arkus-Duntov,** director, high performance vehicle design and development, before the Wayne State University student section, S.A.E., Detroit, title: Corvette Ride and Handling, before the Indiana section, S.A.E., Indianapolis, title: Car Performance and Stability; and before the Columbus, Ohio, section, A.S.M.E., title: Corvette Suspension and Handling; and **William J. Route,** assistant staff engineer, before the A.P.R.A. Institute of Transmission Rebuilders, Cleveland, Ohio, general discussion.

From the GM Engineering Staff: **Roy F. Knudsen,** assistant engineer in charge, Test Facilities Section, before the Instrument Society of America, national meeting, Toronto, Ontario, title: Road Test Simulation in a Dynamometer Test Cell; and **Frank Perna, Jr.,** project engineer, before the I.S.A. Joint Automatic Controls Conference, Boulder, Colorado, title: The Use of the Audio Tape Recorder in Automotive Instrumentation.

S.A.E. Summer Meeting

GM personnel who made presentations at the 1961 S.A.E. summer meeting, St. Louis, Missouri, included: **J. W. Qualman,** assistant chief engineer, Detroit Transmission Division, title: Fluid Coupling; **Hugh A. Williams, Jr.,** supervisor, combustion development, Electro-Motive Division, title: Effect of Engine Design Variables upon Compression Ring Wear as Determined by Radioactive Tracer Technique; **F. H. Walker,** project engineer, Buick Motor Division, title: Multi-Turbine Torque Converters; **D. D. Forester,** assistant experimental engineer, GMC Truck and Coach Division, title: Temperature Control of Truck Cooling System; and **Frank Klco,** senior designer, Oldsmobile Division, title: Theoretical and Practical Aspects of Automotive Brake Design and Testing.

From Chevrolet Motor Division: **Phillip J. Passon,** manager, Engineering Reliability Control Group, title: The Corvette Story; and **D. Paul Fisher,** design engineer, title: The Why and How of Rating Commercial Vehicle Brakes.

From Allison Division: **R. M. Schaefer,** manager, Transmission Engineering, title: Automatic Transmissions for Diesel Engines; **R. W. Sherk,** parts manager, Aircraft Engine and Propeller Operations, title: Allison Unit Exchange System; and **R. W. Guernsey,** engine project engineer, title: Field Experience with the GMT-305 Engine.

From the GM Engineering Staff: **George R. Smith,** assistant engineer in charge, Transmission Development Group, title: A New Concept in Measuring Frictional Characteristics; and **E. W. Upton,** section engineer, title: Application of Hydro-Dynamic Drive Units to Passenger Car Automatic Transmissions.

From GM Research Laboratories: **C. A. Amann,** supervisor, Engineering Development Department and **J. W. Scheel,** senior research engineer, title: Some Experiences with Ground Effect Devices; **J. J. Rodgers,** senior research engineer, and **M. L. Haviland,** research engineer, discussed the paper "A New Concept of Measuring Frictional Characteristics"; and **W. F. Scruggs,** research technician, and **T. W. Selby,** senior research chemist, title: A Technique for Evaluating the Effects of High Frequency Vibrations on Greases Used in Automatic Brake Adjusters.

Bearings

From New Departure Division: **R. E. Murteza**, senior research and development engineer, before the 46th Air Force-Industry Conference, Riverside, California, title: Improved Aircraft Bearing Reliability Through Analysis of Performance and Related Design Factors; and **Robert B. Walker**, project engineer, before the Elliott Corporation, Jeannette, Pennsylvania, the Master Electric Company, Dayton, Ohio, and the A. O. Smith Corporation, Tipp City, Ohio, title: Effect of Ball Bearings on Electric Motor Sound.

Computers

Edward R. McKenna, stress engineer, Fisher Body Division, before the Detroit section, S.A.E., junior activity group, title: Computer Application to Body Design.

From Delco Products Division: Before the A.I.E.E. Technical Conference on Motor Design by Computer, Dayton, Ohio: **Robert W. Leland**, staff engineer, general chairman of conference; and **Dale E. Benedict**, computer project engineer, title: Motor Design Calculations Using the IBM 650.

From GM Research Laboratories: **Donald E. Hart**, head, Data Processing Department, before Michigan Week Technical Symposium, Flint, title: Digital Computers and Their Applications; **Edwin L. Jacks**, assistant head, Data Processing Department, before a Michigan State University Electrical Engineering Department and Computer Laboratory seminar, title: Development of Problem Oriented Language for Computers; **Norman R. Brainard**, senior research engineer, before University of Detroit student sections of A.I.E.E. and I.R.E., title: Fundamentals of Digital Logic Systems; and **C. Richard Lewis**, mathematics programmer, before a University of Michigan group, title: The DYANA Computing System—Extensions and Applications.

Electronics

Hal C. Yost, director of reliability, AC Spark Plug Division, Milwaukee plant, before the Milwaukee Exchange Club, title: A Discussion of the Reliability of Electronic Equipment.

From GM Research Laboratories: **Joseph B. Bidwell**, head, Engineering Mechanics Department, before the Bay of Quinte section, I.R.E., Belleville, Ontario, title: Electronic Applications in Vehicle Design and Operation; and **Frederick Becker**, research engineer, before the New York City section, I.R.E. Professional Group on Vehicle Communications, title: New Electronic Aids to Vehicles.

From Delco Radio Division: **B. J. Gershen**, resident engineer, before the I.R.E. Professional Group on Component Parts, Baltimore, title: Thermal and Voltage Problems—Applications and Trends; and **W. C. Caldwell**, supervisor, field service, before the Kokomo, Indiana, Kiwanis Club, title: Stereo Sound.

From the Defense Systems Division: Before the 4th International Conference on Medical Electronics, New York City: **Kenneth E. Jochim**, Biological Sciences and Systems Department, title: The Development of the Electromagnetic Flowmeter; and **Hampton W. Shirer**, Biological Sciences and Systems Department, title: The Measurement and Recording of Blood Pressure.

Guided Missiles and Space Technology

From the GM Research Laboratories: **Frank E. Jamerson**, senior nuclear physicist, before a thermionic panel of the Electrical Working Group of the Interagency Power Group, Air Force Cambridge Research Laboratories, Bedford, Massachusetts, title: Experimental Techniques of Fabricating and Operating Thermionic Cells, and before the University of Michigan AEC Summer Institute, Ann Arbor, title: Thermionic Conversion of Heat to Electricity; and **Thomas J. Hughel**, supervisor, Metallurgical Engineering Department, before the U.S. Air Force Conference on Beryllium, Wright-Patterson AFB, Ohio, title: Precision Mechanical Properties of Beryllium for Gyro Applications, and before the Polaris Guidance Symposium, Washington, D.C., title: Recent Results on Improved Forms of Beryllium for Gyro Applications.

From Allison Division: **M. C. Hardin**, chief, High Energy Fuels and Combustion Section, before the A.R.S. Liquid Propellants Conference, Palm Beach, Florida, title: Research Rocket Testing of the Lithium-Hydrogen Peroxide System; **B. Agruss**, chief, Applied Chemistry Section, before the Butler University branch, Scientific Society of America and Sigma Xi, Indianapolis, title: Auxilliary Power for Space Units, and, with **E. H. Hietbrink**, senior mathematician, and **R. E. Henderson**, chief, Applied Physics Section, before the 15th Annual Power Sources Conference, Atlantic City, title: Fuel Cells for Energy Storage in Space; **A. J. Sobey**, chief, Rocket Systems Section, and **R. C. Fall**, Advanced Projects Section, before an Army-Navy-Air Force-ARPA-NASA Solid Propellant Meeting, Denver, title: Development of a Solid Propellant Attitude and Velocity Control System for Missiles and Space Vehicles; and **D. G. Gubbins**, Advanced Propulsion Devices Section, and **T. L. Rosebrock**, chief, Advanced Propulsion Devices Section, before the 7th Aero-Space Instrumentation Symposium, Dallas, Texas, title: Switching Problems in Pulsed Electromagnetic Acceleration.

From Defense Systems Division: **Malcom D. Ross**, Biological Sciences and Systems Department, before the Research Reserve Seminar, Great Lakes Naval Training Center, Illinois, title: The Navy Stratolab Program; and **Kaj L. Nielsen**, analytical staff, before a Michigan State University engineering symposium, title: Application of Mathematics to Space Flight.

From AC Spark Plug Division, Milwaukee plant: **B. P. Blasingame**, director of engineering, before members of the Milwaukee section, S.A.E., title: Space Travel—Sense or Nonsense; **Hal C. Yost**, director of reliability, before the Society of Former Special Agents of the FBI, Milwaukee, title: Space Age; **Ronald Clausen**, field service training instructor, before students of Milwaukee Boys' Technical High School, title: Inertial Navigation Requirements; **William A. Gahan**, field service manager, before the Wisconsin section, A.S.C.E., Milwaukee, title: Missiles and Guidance and Some Civil Engineering Aspects; **Hans Hauser**, head, Gyro Project Office, before Trinity Methodist Church Men's Club, Milwaukee: title: Outer Space—Why, How, and When; and the presentation, Inertial Guidance, given by **Eugene Ambroso**, field service instructor, before Don Boscoe High School Science Club, Milwaukee,

and by **Robert G. Brown**, director, ACRD Engineering, before a Rotarian group, Milwaukee.

Leonard E. A. Batz, design engineer, AC Spark Plug Division, before Argentine, Michigan, P.T.A., title: How Rockets and Missiles Will Affect Our Daily Lives.

Highway and Traffic Engineering

From GM Research Laboratories: **Roy S. Cataldo**, senior research engineer, before Purdue University student branches, A.I.E.E.-I.R.E., West Lafayette, Indiana, title: The Electronic Highway and Associated Controls; **Richard W. Rothery**, senior research physicist, before Wayne State University Physics and Mathematics Colloquim, Detroit, title: Theory of Traffic Flow; **Paul L. Olson** and **Herbert J. Bauer**, senior research psychologists, before the Midwestern Psychological Association, Chicago, title: Deceleration Forces in Normal Driving; and before the Operations Research Society, Chicago, **Robert Herman**, head, Theoretical Physics Department, and G. Weiss, title: Recent Research on a Highway Delay Problem, and **Robert Herman** and **Richard W. Rothery**, with L. Edit and R. Foote, title: Analysis of Single Lane Traffic Flow.

Hydraulics

R. R. Jensen, master mechanic, Detroit Transmission Division, before the American Society of Tool and Manufacturing Engineers, Springfield, Illinois, title: History of the Hydra-Matic Automatic Transmission.

Ward F. Diehl, senior project engineer, GM Manufacturing Development Staff, before the Hydraulic Fluid Seminar, Milwaukee, title: A User's Point of View on Hydraulic Fluids.

Lubrication

From GM Research Laboratories: **Fred G. Rounds, Jr.**, senior research engineer, before the A.S.L.E., Philadelphia, a discussion of the paper "The Effect of Temperature in Concentrated Contact Lubrication", by F. W. Smith; and **Paul A. Bennett**, supervisor, Fuels and Lubricants Department, **George K. Malone**, senior research chemist, and **Chester K. Murphy**, research engineer, before the Institute of Petroleum Symposium on the Engine Testing of Crankcase Lubricants, Brighton, England, title: An Engine Test for Predicting the Performance of Engine Lubricants in Most Severe Passenger Car Service.

James H. DeVoe, field engineer, AC Spark Plug Division, before the North Carolina Motor Carriers Association, Charlotte, and before personnel of the Vulcan Corporation, Chicago, title: Oil Filtration.

Manufacturing

Wallace E. Wilson, general manager, Rochester Products Division, before the spring conference, Rochester, New York, chapter, American Institute of Industrial Engineers, title: Evaluating the Results of Production Planning and Control.

Conrad F. Orloff, assistant chief engineer, Chevrolet Motor Division, before the A.S.M.E., Detroit, title: Production Engineering in the Design of the New Car.

Francis A. Cuthbertson, director of production engineering, AC Spark Plug Division, Milwaukee plant, before the Racine, Wisconsin, chapter, A.S.T.M.E., title: Organizing Production Engineering Division Team Approach for Progress.

Charles E. Huggins, general supervisor, Process Engineering Department, Delco Products Division, before the Dayton, Ohio, section, A.I.E.E., title: Problems in Manufacturing Motor Stator Cores.

Arnold L. Boyce, superintendent of processing, Delco Moraine Division, before the Metal Powders Industry Federation, Cleveland, Ohio, title: Safe Handling of Metal Powders.

Gerald E. Johnson, faculty member, General Motors Institute, before the Detroit chapter, American Metals Handling Society, title: Mechanized Decisions.

Paul M. Vos, general supervisor, Reliability Department, Allison Division, before Scientech Club, Indianapolis, title: Product Reliability—How Engineering is Using Numbers to Make Products Last Longer.

Gordon L. Webster, faculty member, General Motors Institute, before the American Society of Quality Control, Toledo, Ohio, title: EVOP Applied to the Resistance Welding of Automotive Sheet Metal.

C. E. Drury, director of sales and engineering, Central Foundry Division, before the Quad City chapter, American Foundrymen's Society, Moline, Illinois, title: Gating to Control the Pouring Rate and the Effect on Scrap.

Mathematics

From GM Research Laboratories: **Henry L. Garabedian**, group head, Mathematics Group, before a Purdue University group, West Lafayette, Indiana, title: Coupled Diffusion Equations: **J. R. Rice**, senior research mathematician, before the American Mathematical Society, Seattle, Washington, title: Algorithms for Tchebycheff Approximation by $ab^x + c$; and **John S. White**, senior research mathematician, before the Institute of Mathematical Statistics, Seattle, Washington, title: Some Monte Carlo Results for the Serial Correlation Coefficient.

Metallurgy

J. H. Lindsay, senior engineer, Ternstedt Division, before the American Electroplaters Society National Convention, Boston, title: Electroplating of Zinc-Base Die Castings in a System Involving Dual Chromium.

From Allison Division: **R. H. Singleton**, supervisor, Ceramic and Cermat Group, **E. L. Bolin**, plant metallurgist, and **F. W. Carl**, assistant chief metallurgist, before the High Temperature Materials Conference, Cleveland, Ohio, title: The Fabrication of Tungsten Shapes by Plasma Arc Spray Techniques.

From GM Research Laboratories: **George H. Robinson**, supervisor, Metallurgical Engineering Department, before the Society for Experimental Stress Analysis, Detroit, title: Some Aspects of Contact Fatigue in Hardened Steel; **Leonard C. Rowe**, senior research chemist, and **Monte S. Walker**, junior research chemist, before the Chemical Specialties Manufacturers Association Conference, Chicago, title: The Effect of Mineral Impurities in Water on the Corrosion of Aluminum and Steel; **William L. Grube**, assistant head, Physics Department, and **Stanley R. Rouze**, senior research physicist, before the Gordon Research Conference on Physical Metallurgy, Meriden, New Hampshire, and before the Detroit chapter, A.I.M.E., title: Growth Studies of Isothermal Transformation Structures of Austenite by Thermionic Emission Microscopy; **Robert F. Thomson**, head,

Metallurgical Engineering Department, before the American Foundrymen's Society, Detroit, title: Aluminum or Iron—Which Shall It Be, and before the American Iron and Steel Institute, Detroit, a discussion on "Trends in Material Requirements in the Automotive Industry as they Affect the Steel Industry"; **C. F. Nixon**, head, Electrochemistry Department, before the American Ordnance Association, Philadelphia, title: On Accelerated Testing; **Joseph V. Laukonis**, senior research physicist, before the NASA Lewis Flight Propulsion Laboratories, Cleveland, Ohio, and before the Gordon Research Conference on Corrosion, New London, New Hampshire, title: The Nature of Oxide Films on Single Crystal Iron Whisker Surfaces; and **Seward E. Beacom**, and **Bernard J. Riley**, senior research chemists, before the International Committee for Electrochemical Thermodynamics and Kinetics, Brussels, Belgium, titles: Experimental Evidence for a Proposed Mechanism of Addition Agent Breakdown and Interaction in Bright Nickel Plating, and Experimental Techniques in the Study of Electrodeposition of Bright Nickel; and before the Organisch-Chemische der Universitat Zurich, Switzerland, the Max Planck Institut fur Metallforschung, Stuttgart, Germany, and the Technische Hochschule, Karlsruhe, Germany, title: The Influence of Organic Addition Agents on Electrodeposition.

Members of the GM Research Laboratories who made presentations at the Symposium on Adhesion and Cohesion, Warren, Michigan, included: **Douglas J. Harvey**, senior research metallurgist, title: The Wetting of Metals by Lead Alloys; **T. J. Mao**, senior research chemist, and **Sidney L. Reegen**, supervisor, Polymers Department, title: Adhesion of Some Acrylic Polymers and Copolymers; **Gust A. Ilkka**, supervisor, Polymers Department, and **Ronald L. Scott**, research chemist, title: Comments on Testing Structural Adhesives; and **Robert N. Fitzwater**, senior research chemist, and **John H. Engel, Jr.**, research chemist, title: Adhesion of Surface Coatings as Determined by the Peel Method.

Research

D. L. Dresser, chief, Applied Physics Section, Allison Division, before the thermionic panel, electrical working group of the Interagency Advanced Power Group, Bedford, Massachusetts, title: Basic Empirical Studies of the Close-Spaced Thermionic Diode.

Raymond A. Pulk, Advanced Planning Department, Defense Systems Division, before the Conference on Nondestructive Analysis of Materials, Warsaw, Poland, and before the Czechoslovakia Academy of Science, Prague, title: The Effect of X-Ray Photon Flux Density on the Fluroscopic Image.

V. A. Nicolia, engineer in charge, Nuclear Heat Transfer Equipment Section, Harrison Radiator Division, before the AEC Meeting on High Temperature Liquid Metal Transfer Technology, Argonne, Illinois, title: Forced Circulation Boiling Mercury Heat Transfer in Tubes.

From GM Research Laboratories: **Thomas P. Schreiber**, senior research physicist, before the Society for Applied Spectroscopy, Chicago, titles: Establishing and Controlling Analytical Curves, and Optical Emission Problem Clinic; **Donald F. Hays**, senior research engineer, before a Yale University group, New Haven, Connecticut, title: Hydrodynamic Theory as Applied to a Finite Journal Bearing; **Arthur A. Vuylsteke**, senior research physicist, before the University of Michigan Nuclear Engineering Department, title: Zeeman Levels in Crystalline Solids; **Charles S. Tuesday**, senior research chemist, before the International Symposium on Chemical Reactions in the Lower and Upper Atmospheres, San Francisco, title: The Atmospheric Photo-Oxidation of Trans-Butene-2 and Nitric Oxide; **Bernard W. Joseph**, senior physics technician, and **Richard F. Majkowski**, research physicist, before the 12th Annual Symposium on Spectroscopy, Chicago, title: The Use of Time-Resolved Spectroscopy in the Investigation of Electrode Phenomena in Sparks; **David E. Martin**, senior research engineer, before the A.S.M.E. Metals Engineering Meeting, Pittsburgh, title: An Energy Criterion for Low Cycle Fatigue; and **Robert Herman**, head, Theoretical Physics Department, before the Wayne State University Physics Colloquim, Detroit, title: Remarks on the Electromagnetic Structure of the Proton and Neutron, and before the National Academy of Sciences, Washington, D. C., title: Electromagnetic Structure of the Proton and Neutron.

From GM Research Laboratories: Before the GM Spectrographic Committee open meeting, Warren, Michigan: **Robert A. Legault**, senior research chemist, title: Corrosion Inhibition; **Thomas O. Morgan**, senior research chemist, title: Theory and Applications of Gas Chromatography; **Albert C. Ottolini**, senior research chemist, title: Determination of Chromium Plate Thickness Using X-Ray Fluorescence; **Thomas P. Schreiber**, senior research physicist, title: Experiences with a Norelco Portable X-Ray Fluorescence Unit; **Richard B. Loranger**, research chemist, title: The X-Ray Fluorescence Analysis of Ferrous Alloys; and **John J. Schultz**, research technician, title: Analysis of Lubricating Oils Using a Direct-Reading Spectrometer.

Technical Careers and Vocational Guidance

H. E. Helms, supervisor, Rocket Engines-Applied Mechanics, Allison Division, before the Purdue University Extension, Indianapolis, title: Career in Space Exploration.

Carl R. Queck, senior process engineer, Fisher Body Division, before students of Rochester, Michigan, High School, title: Drafting as a Profession.

Robert W. Decker, works manager, Rochester Products Division, before a career night, Wayne Central School, Ontario Center, New York, title: Manufacturing Trades.

James R. Egan, materials engineer, Chevrolet Motor Division, before students of Michigan State University, title: Opportunities in Metallurgy.

J. J. Rosalik, senior project engineer, Cadillac Motor Car Division, before the vocational guidance forum, St. Alphonsus Parish, Dearborn, Michigan, title: Drafting as a Career.

Frank C. Fleck, project engineer, GMC Truck and Coach Division, before students of St. Frederick School, Pontiac, Michigan, title: The Challenge of Engineering.

M. V. Cannon, Jr., process engineer, Buick-Oldsmobile-Pontiac Assembly Division, before the A.S.M.E., Shreveport, Louisiana, title: The Mechanical Engineer in Industry.

From Frigidaire Division: **A. J. Scholl**, chief draftsman, refrigerated appliances engineering, before students of Vandalia, Ohio, Butler High School, title: Drafting as a Profession. Before students of Trotwood, Ohio, Madison

High School: **James W. Jacobs**, manager, research and future products engineering, title: Engineering as a Career, and **Carl M. Schell**, assistant general supervisor—drafting, title: A Career in Drafting.

From AC Spark Plug Division: **Trevor Jones**, head, equipment group, before the North Shore Kiwanis Club, Milwaukee, title: Vocational Opportunities in Physics; **Joseph M. Biedenbach**, senior experimental physicist, before the GMC Truck and Coach Technical Club, Pontiac, Michigan, title: Challenge to Youth; **Thomas Jarcho**, instructor, technical education, before senior students, West Division High School, Milwaukee, title: Electrical Engineering as a Vocation; and **Robert G. Brown**, director, ACRD Engineering, before the Milwaukee Greenfield High School Science Club, title: Questions and Answers on Careers; and **Sid S. Hatch**, director, Engineering Services, before members of the Engineers' Society of Milwaukee, title: Engineering Opportunities in Management.

Transistors

From Delco Radio Division: **William E. Thompson**, supervisor, Applied Mathematics, before the Minuteman Component Reliability Symposium, Los Angeles, title: Analytical Screening Techniques for High Reliability Transistors; **J. O. Beasley**, field service engineer, before the Television and Electronics Service Association of Kansas, Wichita, title: Transistor Fundamentals and Troubleshooting; **B. C. Hanrahan**, field service engineer, before the New Jersey Vocational School Instructors, Union, title: Transistor Fundamentals, Circuits, and Electronic Devices; **J. F. Martin**, field service engineer, before personnel of Missile Division, North American Aviation, Downey, California, title: Transistor Fundamentals and Circuits; **B. J. Gershen**, resident engineer, before personnel of the Martin Company, Orlando, Florida, and before personnel of Minneapolis-Honeywell, St. Petersburg, Florida, title: Power Transistor Applications; and **P. R. Powell**, field service engineer, before the Future Farmers of America, Kokomo, Indiana, and before the Pittsburgh, Pennsylvania, Radio and Television Service Association, title: Transistor Fundamentals and Troubleshooting.

Miscellaneous

Max Ephraim, Jr., assistant chief engineer, Electro-Motive Division, before an A.S.E.E. panel at the Illinois Institute of Technology, Chicago, title: Reviewing the Mechanical Engineering Curricula.

Max M. Roensch, assistant chief engineer, Chevrolet Motor Division, before the Michigan Petroleum Association, Grand Rapids, title: Tomorrow's Automobile and Its Effect on Petroleum Marketing.

George P. Hanley, assistant general supervisor—drafting, Detroit Diesel Engine Division, before the Michigan section, Classic Car Club of America, Pontiac, title: The Marmon Story.

T. A. Prewitt, senior project engineer, Delco Radio Division, before students of Maple Crest High School, Kokomo, Indiana, title: Measurement of Human Reaction.

Ray Fisco, junior process engineer, Brown-Lipe-Chapin Division, before the 35th Annual Ohio Water Pollution Control Convention, Cleveland, title: Treatment of Industrial Plating Wastes.

From Delco Products Division: **William J. Wagner**, general sales manager, before the Electrical Apparatus Service Association, San Francisco, title: Motortown, U.S.A.; **Claude M. Willis**, safety director, before Ohio Civitan Club presidents and presidents-elect, Middletown, title: Safety Projects—All Types; and **John P. Flanagan**, senior methods engineer, before the Foremen and Supervisors Conference, The Ohio State University, Columbus, title: Supervising Women in Industry.

Robert J. Valentine, supervisor, aircraft applications, New Departure Division, before engineering personnel of the Pesco Products Division, Borg Warner Corporation, Bedford, Ohio; the Jack and Heintz Company, Cleveland; and the Thompson-Ramo-Wooldridge Company, Cleveland, title: New Departure Laboratory Facilities.

From Allison Division: **J. M. Wetzler**, project manager, small gas turbine engines, before the aviation division meeting, A.S.M.E., Los Angeles, title: Development of the T63 Engine; **G. V. Bianchini**, senior experimental engineer, before groups from the F.A.A. and U.S.C.G., Washington, D. C., title: The Effects of Bird Ingestion on Gas Turbine Engines; and **L. A. Roudebush**, section chief, engineering records and reproduction services, before the National Microfilm Association, Chicago, title: Industry Looks at the Department of Defense Microfilm Program.

From Delco Appliance Division: **Ralph Lingg**, general supervisor, tool engineering, before the Rochester, New York, chapter, National Tool Die and Precision Machine Association, title: What We Want from the Tool and Die Salesman; **Donald Patterson**, tool and die engineer, before the Patty Hill Grade School, Rochester, New York, title: English History and Geography; and **C. T. Linder**, supervisor—Research laboratory, before the Brighton, New York, High School Physics Club, title: Energy Conversion.

From AC Spark Plug Division: **Harold S. Sharp**, technical librarian, before the Graduate School of Library Science, University of Wisconsin, Madison, title: The Business Aspects of Special Librarianship, and before the American Management Association, New York City, title: Engineering Data Storage and Retrieval; and **Henry C. Stuerzl**, staff engineer, before the Society of Plastic Engineers, Detroit, title: Instrument Cluster Plastics.

From Defense Systems Division: **Richard C. Kaehler**, land operations, before the 2nd Annual Meeting, International Studies Association, Boulder, Colorado, and before faculty members of the Air Force Academy, Colorado Springs, title: A Systems Engineering Approach to the Problems of Internation Conflict; and **Allen V. Butterworth**, systems evaluation, before Air Force Reserves, Selfridge AFB, Michigan, title: Nuclear Weapons Effects.

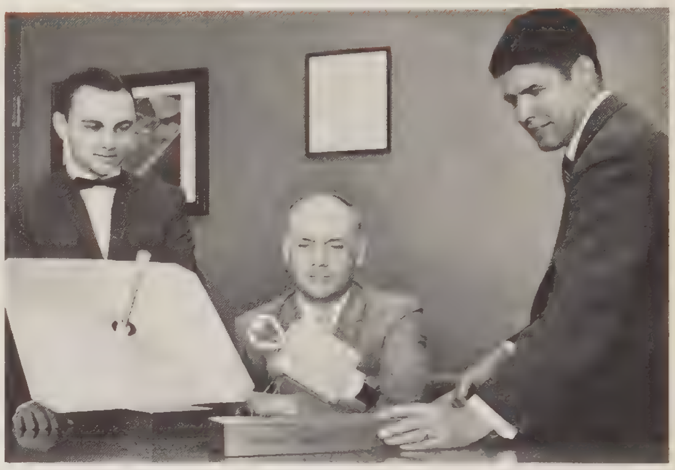
From GM Research Laboratories: **Eugene B. Jackson**, librarian, before the Boston and Cincinnati chapters, Special Libraries Association, title: Special Libraries to 1980; and **Willard D. Cheek**, senior research physicist, before the A.S.L.E., Detroit, title: Fission, Fusion, and Confusion, before the Dayton, Ohio, Business, Industry and Educators Day Conference, title: Take Command, and before an Eastern Michigan University group, title: Science and Gadgetry.

From General Motors Institute: **Harold P. Rodes**, president, before the Work-Study Programs in Higher Education Conference, Princeton University, title: The Education Advantages of Coopera-

tive Education; **Leonard B. Wocholski**, chairman, Science-Energy Department, before A.S.M.E. summer meeting, Los Angeles, title: Seven Basic Principles of Safety; **Thomas W. Pisel**, area supervisor, plant management training, before the training council, Manufacturers' Association, Syracuse, New York, title: The Total Role of the Training Director as an Educator; **Elon L. Clark**, faculty member, before the Adelphian Academy, Holly, Michigan, titles: Personality Development, and Achieving Maturity; **Paul W. Stone**, faculty member, before the West Flint Kiwanis Club, title: Fallout Shelters; **Roger P. Wilcox**, faculty member, before an American Institute of Biological Sciences seminar, Washington, D. C., title: Oral Technical Reporting; **Adolph A. Klautsch**, senior specialist, before the central Indiana chapter, Industrial Engineers Society, Lafayette, title: Reducing Tensions, and before a safety directors meeting, Flint, title: Human Factors in Safety Campaigns; and **Harold O. Haskitt, Jr.**, section head, Speech Department, before the University of Michigan summer speech conference, title: The First College Speech Course: Content and Procedures, and before the Central States Speech Association annual convention, Chicago, title: The Company-Centered Program.

1961 General Motors Conference for Engineering and Science Educators

During a Conference session at the GM Technical Center, Dr. John E. Lagerstrom (center), Iowa State University assistant dean of engineering, visits a hydraulic flow table at the Engineering Staff. With him are Engineering Staff employes Ernest W. Upton (left) and Kenneth E. Brooker (right).



At Allison Division during his Conference field assignment, Dr. Robert L. Henry (center), physics department chairman, Wabash College, examines small scale models of solar reflector devices. With him are Allison employes Robert E. Stewart (left) and Dr. Robert E. Henderson (right).

Educators attending the Tenth GM Conference for Engineering and Science Educators were: Kneeling—Robert K. Patterson, University of Massachusetts; T. Clyde Banfield, General Motors Institute; Walter R. Debler, University of Michigan; Duane D. McKeachie, General Motors Institute; Paul E. Stanley, Purdue University; Jacob H. Sarver, University of Cincinnati; William D. O'Connell, The Pennsylvania State University; Georges V. Tordion, Laval University; Jesse H. Wilder, University of Dayton; John E. Lagerstrom, Iowa State University; Standing—Ross D. Young, University of Missouri; Ivan A. Planck, Indiana Technical College; Bob A. Jessup, Detroit Institute of Technology; Roy O. Mesick, Western Michigan University; E. Kent Springer, University of Southern California; Arthur J. Pulos, Syracuse University; J. Harvey Kleinheksel, Hope College; Robert H. Nau, Missouri School of Mines and Metallurgy; Samuel C. Wheeler, Jr., Denison University; Walter H. Bauer, Rensselaer Polytechnic Institute; Alfred C. Ingersoll, University of Southern California; T. W. W. Stewart, University of Western Ontario; Lloyd F. Rader, University of Wisconsin; Milton O. Peach, Michigan College of Mining and Technology; Roger R. Borden, Worcester Polytechnic Institute; Howard L. Womochel, Michigan State University; Edgar C. Clark, The Ohio State University; Marvin S. Carr, Eastern Michigan University; Thomas J. Dolan, University of Illinois; Forest E. Brammer, Wayne State University; Alfred O. Schmidt, Marquette University; Arthur C. Haman, University of Detroit; Donald R. Brutvan, University of Buffalo; Robert L. Henry, Wabash College. The purpose of the Conference, held in Detroit July 9-21, was to acquaint educators with GM product, production, and research activities.

A Typical Problem in Computer Programming:

Develop a Program to Compute Heat Exchanger Effectiveness

By PAUL K. BEATENBOUGH
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A forced convection, crossflow heat exchanger is one in which the flow direction of two fluid mediums is perpendicular. When computing the performance of such an exchanger, it is necessary to evaluate an infinite series representing the heat exchanger effectiveness. The problem presented here is to develop a computer program which can be used to compute the heat exchanger effectiveness, taking into account the available information, the results sought, and certain imposed restrictions. The problem is derived from a larger program used by the Harrison Radiator Division.

An infinite series must be applied to compute the effectiveness

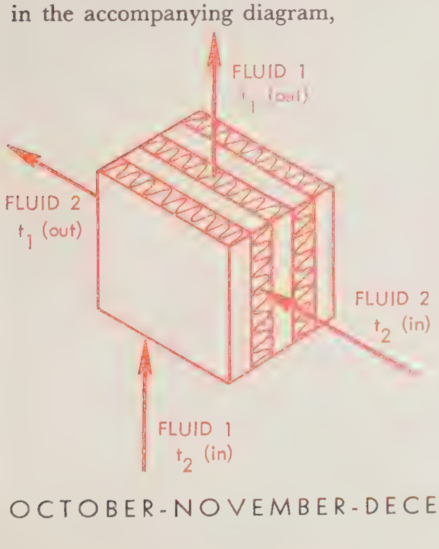
THE forced convection heat exchanger is a device used to transfer heat from one fluid stream to another. The two fluids, each at a different temperature, flow in spaces which are separated by a conducting wall. Heat is transferred from the fluids to the wall by convection and through the wall by conduction. The heat transfer between the two fluid mediums through the conducting wall is determined by applying the familiar rate equation

$$H = (U)\ (A)\ (\Delta t_m) \qquad (1)$$

where

H = heat transfer rate (Btu per min)
U = overall heat transfer conductance (Btu) per (min) (F) (ft²)
A = effective heat transfer area (ft²)
Δt_m = mean temperature difference (F).

The two fluids may flow through a heat exchanger in the same direction (parallel flow arrangement), counter to each other (counterflow arrangement), or in a crossflow arrangement, where the two fluids flow either perpendicular or oblique to each other. A pure crossflow arrangement is one where the two fluids flow at 90° to each other, as illustrated in the accompanying diagram,



where

$t_{1(in)}$ = inlet temperature of fluid *1* (F)

$t_{1(out)}$ = outlet temperature of fluid *1* (F)

$t_{2(in)}$ = temperature of fluid *2* into the heat exchanger (F)

$t_{2(out)}$ = temperature of fluid *2* out of the heat exchanger (F).

For heat exchangers having either counterflow or parallel flow arrangements, the mean temperature difference Δt_m may be derived simply in logarithmic form[1]. For a crossflow heat exchanger arrangement, however, the temperature distribution is complex and the mean temperature difference Δt_m must be calculated by applying an infinite series. Two infinite series have been derived for the crossflow heat exchanger, one by Nusselt[2] and one by Mason[3]. For the problem to be presented, Nusselt's series will be used.

In the design procedure used by Harrison Radiator Division for forced convection heat exchangers having a crossflow arrangement, equation (1) is not used directly to compute the heat transfer rate. Rather, the heat exchanger effectiveness η is calculated. The heat exchanger effectiveness is defined as the ratio of the temperature change of one fluid to the inlet temperature difference. A heat exchanger, therefore, has two values for η, one for each fluid.

The heat exchanger effectiveness for fluid *2* is

$$\eta_2 = \frac{[t_{2(in)} - t_{2(out)}]}{[t_{2(in)} - t_{1(in)}]} = \frac{\Delta t_2}{ITD} \qquad (2)$$

where

η_2 = heat exchanger effectiveness for fluid *2* (dimensionless)
Δt_2 = temperature change of fluid *2*
$\Delta t_2 = [t_{2(in)} - t_{2(out)}]$
ITD = inlet temperature difference = $[t_{2(in)} - t_{1(in)}]$.

The energy exchanged between the two fluids appears as an enthalpy change in each fluid. When no change of state occurs, the enthalpy change rate is equal to the product of the mass flow rate, the specific heat, and the temperature change of either fluid. The enthalpy change for fluid *2* may be calculated as

$$H = (m_2)\ (c_{p2})\ [t_{2(in)} - t_{2(out)}],$$

or

$$H = (m_2)\ (c_{p2})\ (\Delta t_2) \qquad (3)$$

where

H = heat transfer rate (Btu per min)
m_2 = mass flow rate of fluid *2* (lb per min)
c_{p2} = specific heat, at constant pressure, of fluid *2* (Btu) per (lb) (F).

Substituting the value for Δt_2 from equation (2) into equation (3) gives

$$H = (m_2)\ (c_{p2})\ (\eta_2)\ (ITD). \qquad (4)$$

Equating values of H from equations (1) and (4) gives the following expression for the mean temperature difference Δt_m:

$$\Delta t_m = \frac{(m_2)\ (c_{p2})\ (\eta_2)\ (ITD)}{(U)\ (A)} \qquad (5)$$

Nusselt's series expresses the heat exchanger effectiveness η as a function of the mass flow rates and the specific heats

$$= e^{-b}$$

$$- \left[\frac{be^{-b}}{1!}\right]\left[1 + \frac{e^{-a}}{a} - \frac{1}{a}\right]$$

$$= \left[\frac{b^2 e^{-b}}{2!}\right]\left[\left(1 + \frac{e^{-a}}{a} - \frac{1}{a}\right) + \left(e^{-a} + \frac{e^{-a}}{a} - \frac{1}{a}\right)\right]$$

$$= \left[\frac{b^3 e^{-b}}{3!}\right]\left[\left(1 + \frac{e^{-a}}{a} - \frac{1}{a}\right) + \left(e^{-a} + \frac{e^{-a}}{a} - \frac{1}{a}\right) + \left(\frac{a}{2} e^{-a} + e^{-a} + \frac{e^{-a}}{a} - \frac{1}{a}\right)\right]$$

$$\left[\frac{b^4 e^{-b}}{4!}\right]\left[\left(1 + \frac{e^{-a}}{a} - \frac{1}{a}\right) + \left(e^{-a} + \frac{e^{-a}}{a} - \frac{1}{a}\right) + \left(\frac{a}{2} e^{-a} + e^{-a} + \frac{e^{-a}}{a} - \frac{1}{a}\right) + \left(\frac{a^2}{6} e^{-a} + \frac{a}{2} e^{-a} + e^{-a} + \frac{e^{-a}}{a} - \frac{1}{a}\right)\right]$$

Table I—Defined here are the terms $\Psi_0, \Psi_1, \Psi_2, \Psi_3$, and Ψ_4 used in Nusselt's series for computing the heat exchanger effectiveness.

	η_2						
a	0.25	1.000	2.500	5.000	7.500	10.000	e^{-b}
250	0.1985	0.1470	0.0892	0.0494	0.0333	0.0250	0.7788007831
000	0.5880	0.4762	0.3241	0.1936	0.1327	0.0999	0.3678794412
500	0.8918	0.8102	0.6525	0.4508	0.3253	0.2486	0.0820849986
000	0.9885	0.9680	0.9017	0.7509	0.6024	0.4835	0.0067379470
500	0.9988	0.9950	0.9758	0.9035	0.7957	0.6805	0.0005530844
000	0.9999	0.9993	0.9946	0.9671	0.9074	0.8277	0.0000453999

Table II—The values listed here for η_2 and e^{-b} for a range of values for a and b are to be used as an aid in checking the program to be developed for computing the heat exchanger effectiveness. The values were obtained from a program more complex than the one to be developed in the problem.

of the two fluid mediums and the overall conductance of the heat exchanger. For convenience, the following definitions can be established:

$$a = (NTU)_1,\ b = (NTU)_2$$

where

$(NTU)_1$ = number of heat transfer units for fluid 1 = UA/m_1c_{p1} (dimensionless)

$(NTU)_2$ = number of heat transfer units for fluid 2 = UA/m_2c_{p2} (dimensionless)

a and b are identical to $(NTU)_1$ and $(NTU)_2$, respectively.

The heat exchanger effectiveness can be conveniently expressed as a function of the heat transfer unit, which is the dimensionless ratio UA/mc_p.

The solution for Nusselt's series is

$$\eta_2 = 1 - \sum_{\eta=0}^{\eta=\infty}(\Psi_0 + \Psi_1 + \Psi_2 + \ldots \Psi_n)$$

where

Ψ_0, Ψ_1, Ψ_2, Ψ_n have values as defined in Table I.

Problem

The problem is to write a computer program for computing the heat exchanger effectiveness η_2, accepting a and b as input and supplying a, b, and η_2 as output. The usual procedure at Harrison Radiator is to use the problem presented here as a sub-routine in a larger and more complex program.

Both a and b are to be expressed as XX.XXX and are not to exceed 10.000. The heat exchanger effectiveness η_2 is to be computed as X.XXXX. It should be noted that η_2 cannot exceed unity, as indicated by equation (2).

One caution is in order when working with a non-floating point computer with a 10-digit word length. For large values of x, the value of e^{-x} will be quite small. For example, e^{-10} = 0.0000454. When working in fixed point arithmetic it is necessary to use as many decimal places as is possible to retain accuracy in the final solution. The maximum number of decimal places in e^{-x} that can be used with single precision arithmetic is, of course, 10. It is suggested that e^{-x} be computed to this precision. This will require the use of double precision arithmetic (20 places) in the computation of e^{-x}. In the remainder of the program, single precision arithmetic should be used, retaining as many decimal places as possible.

Since values are required for e^{-a} and e^{-b}, a sub-routine should be written to compute e^{-x} in double precision arithmetic with appropriate linkages to the program for the heat exchanger effectiveness.

As an aid in checking the program to be developed, Table II lists values of η_2 and e^{-x} for a range of values of a and b.

The program to be presented will be that used for a basic IBM 650 digital computer. The logic of the program, however, is applicable to any stored program computer. Suitable modifications can be made in the development of the program to take advantage of special features provided by specific computers.

The solution to the problem will be presented in the January-February-March 1962 issue of the General Motors Engineering Journal.

Bibliography

1. Jakob, Max and Hawkins, G. A., *Elements of Heat Transfer* (New York: John Wiley and Sons, Inc., 3rd Edition, 1957), p. 173.

2. Nusselt, Wilhelm, "A New Heat Transfer Formula for Crossflow," *Technische Mechanik und Thermodynamik*, Vol. 1, No. 12 (December 1930), A.T.R. Translation No. 279.

3. Mason, John L., *Heat Transfer in Crossflow*, Proceedings of the 2nd U.S. National Congress of Applied Mechanics, 1954.

Solution to the Previous Problem:

Define the Geometry of the Inner and Outer Tooth Contours of a Gear Type Oil Pump

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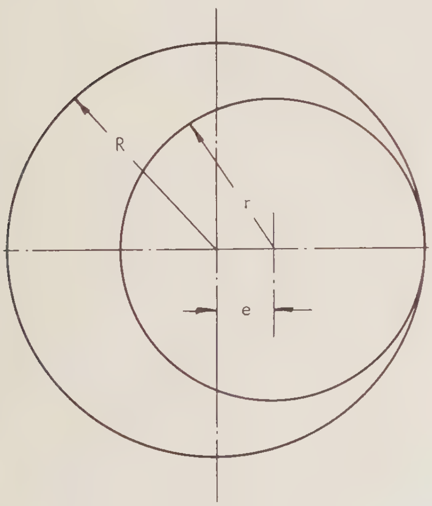
An important design aspect of a gear type rotary pump having an inner and outer rotor is that the lobes of the rotors must be in theoretical contact at all times. If the contour of the lobes is considered to be based on an approximate hypocycloidal curve, parametric equations can be derived which prove that the lobes are in constant contact. The equations developed also can be used when applying data processing facilities to provide for precision machining of the tools used to manufacture the rotors.

Equations show inner and outer rotors are in constant contact

THE hypocycloid for either the inner or outer rotor is produced by the trace of a given point on the generating circle as it rolls around the inside of the pitch circle. Any mating pair of rotors must have a common generating circle and be related as shown in the following figure



where

- R = radius of the pitch circle for the outer rotor
- r = radius of the pitch circle for the inner rotor
- e = distance between rotor centers
- $e = R - r$.

If the number of cusps of the inner rotor hypocycloid is n and the number of cusps of the outer rotor hypocycloid is $n + 1$, the following relationship will exist for any given pair of rotors:

$$\frac{r}{R} = \frac{n}{n+1}$$

Therefore,

$$R = (n+1)e$$
$$r = ne.$$

Parametric equations can be established which will define the hypocycloid for the outer rotor having $(n + 1)$ lobes, or teeth. Referring to Fig. 1, and considering the center of the hypocycloid to be at the origin, the equations for the separate coordinate systems are

$$x = (R - e)(\cos\theta) + (e)(\sin\phi)$$
$$y = (R - e)(\sin\theta) - (e)(\cos\phi).$$

The radius R of the outer rotor is

$$R = (n+1)e,$$

and the angle ϕ shown in Fig. 1 can be expressed as

$$\phi = 180° - (90° - \theta) - (n+1)\theta$$
$$\phi = 90° - n\theta.$$

Substituting these values for R and ϕ into the preceding equations for x and y gives

$$x = (ne)(\cos\theta) + (e)\sin(90° - n\theta)$$
$$y = (ne)(\sin\theta) - (e)\cos(90° - n\theta).$$

Or,

$$\left.\begin{aligned} x &= (ne)(\cos\theta) + (e)(\cos n\theta) \\ y &= (ne)(\sin\theta) - (e)(\sin n\theta). \end{aligned}\right\} \quad (1)$$

Equations (1) define the hypocycloid for the outer rotor having $(n + 1)$ lobes when the center of the hypocycloid is at the origin.

This approach can be mathematically substantiated if the pitch diameter of the inner rotor is considered to be a generating circle as it rolls around the inside of the pitch circle of the outer rotor (Fig. 2). This is exactly the motion which takes place during actual operation of the type of gear pump under consideration. As the generating circle rolls in a counterclockwise direction, a given point P on the circle will trace out a curve in a clockwise direction (line P_1-P, Fig. 2). Parametric equations for this curve are

$$x = (R - r)(\cos\alpha) + (r)(\sin\gamma)$$
$$y = (R - r)(\sin\alpha) - (r)(\cos\gamma).$$

The radii R and r have been defined as

$$R = (n+1)e$$
$$r = ne,$$

and the angle γ (Fig. 2) is equal to

$$\gamma = 180° - (90° - \alpha) - \left(\frac{R}{r}\right)\alpha$$

$$\gamma = 90° - \frac{\alpha}{n}$$

Substituting these values for R, r, and γ into the preceding equations for x and y gives

$$x = (e)\ (\cos\ \alpha) + (ne)\left[\sin(90° - \frac{\alpha}{n})\right]$$

$$y = (e)\ (\sin\ \alpha) - (ne)\left[\cos(90° - \frac{\alpha}{n})\right]$$

Or,

$$\left.\begin{aligned} x &= (e)\ (\cos\ \alpha) + (ne)\left[\cos\frac{\alpha}{n}\right] \\ y &= (e)\ (\sin\ \alpha) - (ne)\left[\sin\frac{\alpha}{n}\right]. \end{aligned}\right\} \quad (2)$$

The first arc of the hypocycloid will be completed when the angle α increases such that the line OT (Fig. 2) coincides with the line CP. The point P will then be closed to the point P_n. This will occur when

$$\left(\frac{R}{r}\right)\alpha = 360°,$$

or

$$\alpha = \frac{(r)\ 360}{R}$$

To complete a hypocycloid of $(n + 1)$ cusps, therefore, the line OT must rotate through

$$\frac{(n + 1)(r)\ 360°}{R}$$

This expression reduces to n revolutions when the previously defined values for R and r are substituted.

The angle between the geometric center of the rotor and the center of the generating circle (angle θ, Fig. 3) equals 360° for one complete revolution of the generating circle. The relationship, therefore, between angle θ and angle α is

$$\frac{\theta}{\alpha} = \frac{1}{n}, \text{ or } \alpha = n\theta.$$

Substituting this value for α into equations (2) gives

$$x = (e)\ (\cos n\theta) + (ne)\left(\cos\frac{n\theta}{n}\right)$$

Fig. 2—The pitch diameter of the inner rotor, of radius r, is the generating circle as it rolls around the inside of the pitch circle of the outer rotor of radius R. As this generating circle rolls around in a counterclockwise direction, a given point P on the circle traces a hypocycloidal curve in a clockwise direction, as indicated by the line P_1-P. The center of the outer rotor is at point O and the center of the inner rotor is at point C. Angle α indicates the amount of counterclockwise rotation the circle of radius r has rolled on the pitch circle of radius R, starting from the point where P coincided with P_1. In the amount of rotation indicated by angle α, the portion P_1-P was generated. Point T indicates the point of tangency of the two circles after α degrees of rotation. The line O-T is a line through the centers of the two circles and their point of tangency. Line C-P connects the center of the smaller circle of radius r with the point P which is generating the larger hypocycloid. The angle γ is merely an angle in the auxiliary right triangle whose hypotenuse is C-P. The Point P_n indicates the point to which P will have progressed when the angle β first becomes 180°. The point P_n, therefore, locates the first cusp generated beyond P_1. To the right of the figure is a derivation for the angle β.

Fig. (3)—The outer rotor (a) and inner rotor (b) have a common generating circle A of radius e. The pitch radius of the outer rotor is R and the pitch radius of the inner rotor is r. The dimension s is the normal distance between either hypocycloid and the actual lobe contour. Angle θ is the angle between the geometric center of the rotor and the center of the generating circle and equals 360° for a complete revolution of the generating circle. The cusps of the hypocycloid of the inner rotor lie on the hypocycloid of the outer rotor at points P_1 through P_7 (c). The inner rotor is the driven member and rotates on a shaft about its geometric center. The outer rotor also rotates about its geometric center, which is eccentric to the center of the inner rotor by a distance e.

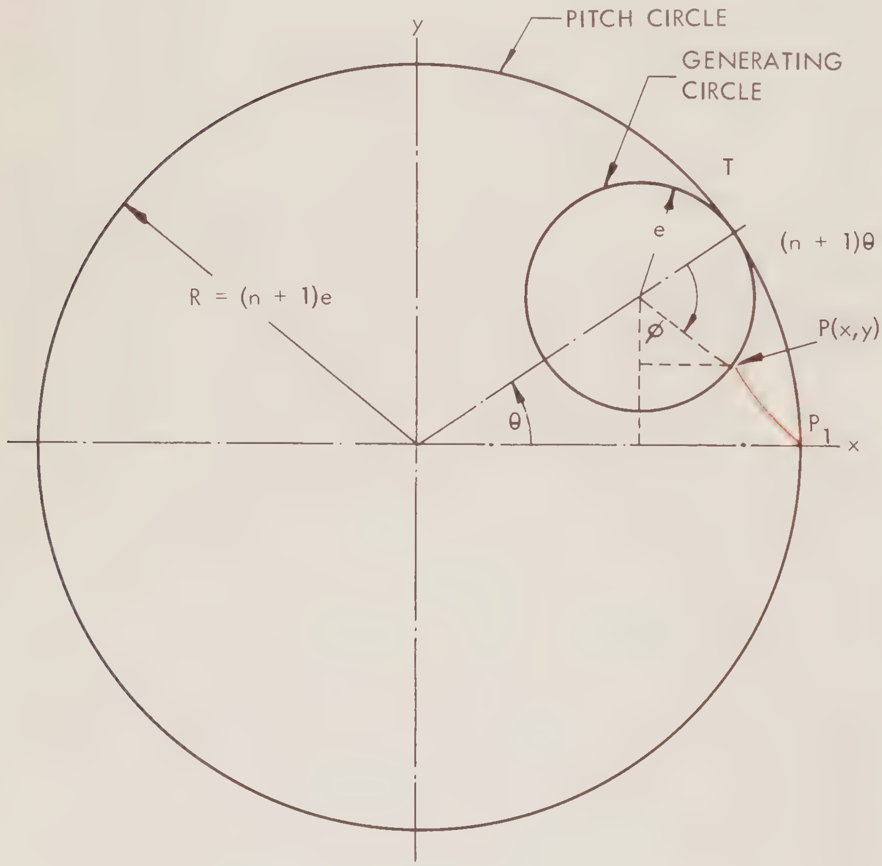
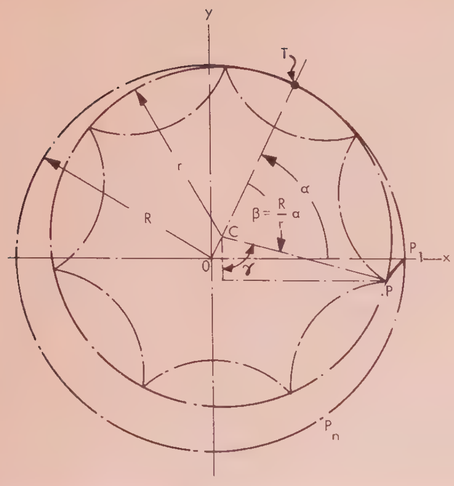


Fig. 1—The arc P_1-P is a portion of the hypocycloid of the outer rotor which is generated as the generating circle rolls through the angle θ. Since there is no slippage between the two circles, the arcs P_1-T and P-T are of equal length. The drawing here, however, has been distorted somewhat for purposes of clearer visualization.



LET

ANGLE $P_1OT = \alpha$ (RADIANS)

ANGLE PCT $= \beta$ (RADIANS)

SINCE THE SMALLER PITCH CIRCLE ROLLS ON THE LARGER PITCH CIRCLE,

ARC LENGTH PT = ARC LENGTH P_1T.

THEREFORE,

$$\alpha = \frac{P_1T}{R} \quad \text{AND} \quad \beta = \frac{PT}{r}.$$

OR,

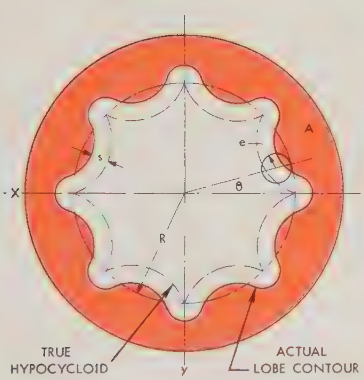
$$P_1T \cdot R\alpha \quad \text{AND} \quad PT = r\beta$$

ALSO,

$$r\beta = R\alpha$$

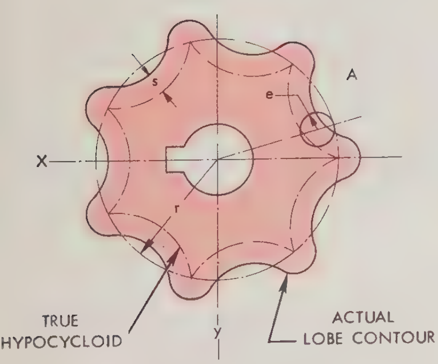
THEREFORE,

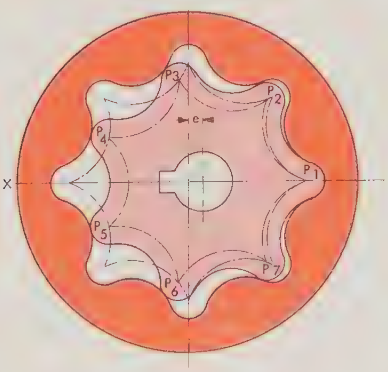
$$\beta, \text{ OR ANGLE PCT} = \frac{R}{r}\,\alpha$$



a

b





c

$$y = (e)\,(\sin n\theta) - (ne)\left(\sin \frac{n\theta}{n}\right)$$

These two equations simplify to

$$\left.\begin{aligned} x &= (ne)\,(\cos\theta) + (e)\,(\cos n\theta) \\ y &= (ne)\,(\sin\theta) - (e)\,(\sin n\theta)\,. \end{aligned}\right\} \quad (3)$$

A comparison of equations (1) and (3) shows that the abscissa equations are identical while the ordinate equations differ only in algebraic sign. Since the curves represented by equations (1) and (3) are symmetrical to the x-axis, the significance of the minus sign in equations (3) is that the curve is being generated in a negative angular direction (clockwise rotation) instead of in a positive direction, as in equations (1). It can be concluded, therefore, that Fig. 3c is verified and that the inner and outer rotors are at all times in theoretical contact.

Conclusion

The parametric equations defining the hypocycloids for the outer and inner rotors, therefore, are as follows.

For the Outer Rotor

$$x = (ne)\,(\cos\theta) + (e)\,(\cos n\theta)$$

$$y = (ne)\,(\sin\theta) - (e)\,(\sin n\theta)$$

For the Inner Rotor

$$x = (n - 1)\,e\,(\cos\theta) + e\,[\cos\,(n - 1)\,\theta]$$

$$y = (n - 1)\,e\,(\sin\theta) - e\,[\sin\,(n - 1\,\theta]\,.$$

In the preceding equations, n and e must be in accordance with the relationships described at the beginning of the solution for any mating pair or rotors having a common generating circle.

One important advantage in having the inner and outer rotors defined analytically is that data processing facilities could be used in further studies on the subject. For example, a program defining the contours could readily be prepared and fed into a punch-card operation which would serve to control the precision machining of tools used to manufacture the rotor teeth.

Contributors to Oct.-Nov.-Dec. 1961 Issue of

GENERAL MOTORS ENGINEERING JOURNAL

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Mr. Common joined the G.M.I. faculty in 1958. Prior to that time he was employed by AC Spark Plug Division as a project engineer. Some of his projects at AC included the evaluation of missile ground support equipment and the development of a polyurethane air cleaner.

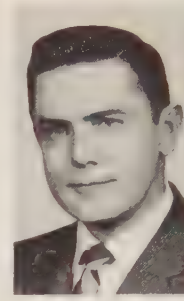
Mr. Common was granted a B.S. degree from Tri-State College in 1953. He is a member of the Institute of Radio Engineers and the American Institute of Electrical Engineers. He also is a member of the General Motors Instrumentation Committee.

Prior to joining GM, Mr. Common was employed by the Bendix Aviation Corporation where he did work on electrohydraulic servomechanisms and microwave guidance for missiles and fuel controls for jet engines.

DR. FRANCIS FARAGO, contributor of "Gaging Roller Bearing Components by Electronic Contour Tracings," is a senior research engineer in the Advanced Design, Research and Development Department at Hyatt Bearings Division. He joined Hyatt in 1959 with assignments in manufacturing research on the staff of the Works Manager, and was promoted to his present position in 1960. He is engaged in the refinement of roller bearing design specifications based on original explorations of the functional effects of variations in critical component characteristics.

Dr. Farago has had diverse experience in the machine tool field and in the manufacture of antifriction bearings, much of it in Hungary prior to 1956. He held technical and managerial positions there both in industry and in government agencies.

After undergraduate and post-graduate schooling in France (Universite de Dijon) and in Belgium (Institut Technique Superieur), Dr. Farago received his doctorate, cum laude, from the Technical University of Budapest in 1935. He has published several technical books in Hungary, and has contributed papers to Hungarian journals. A member of the American Society for Metals, he has held membership in several Hungarian technical societies, including the Scientific Society of Engineering. He has several patents for cutting tools and metalworking equipment registered in Hungary.



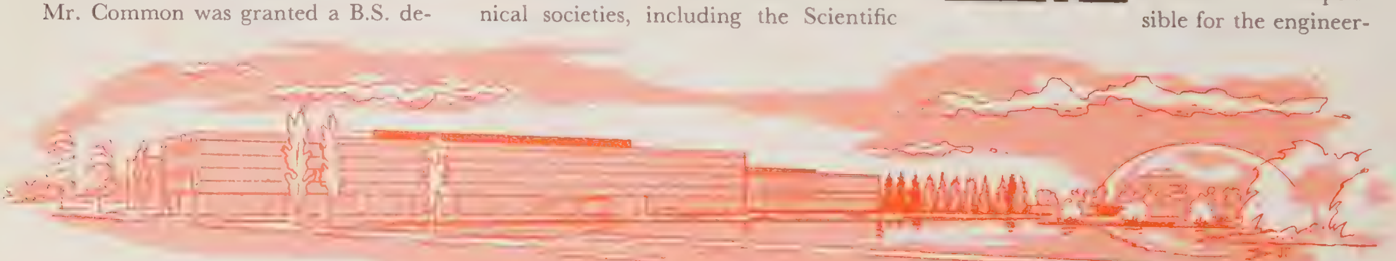
JOHN T. HOBAN, contributor of "A Design Summary of the Cadillac Front Suspension System," is an assistant staff engineer at Cadillac Motor Car Division. He originally joined General Motors in 1947 as an experimental engineer with Delco Products Division. In 1950 he was transferred to Cadillac as a senior project engineer. He assumed his present position in 1956.

As assistant staff engineer, Mr. Hoban is responsible for the design and development of both current and future frames, suspension systems, steering systems, wheels, and tires. He also is responsible for Cadillac's commercial chassis and for complete chassis layouts.

Some of his past major projects have included developmental work on the Cadillac air suspension system and the development of frame structures for improved ride and shake control.

Mr. Hoban received the B.M.E. degree from the University of Dayton in 1943. He is a member of the Society of Automotive Engineers and is a member of the Society's Spring Committee and chairman of its Air Spring Subcommittee. His work in the suspension field has resulted in the grant of two patents.

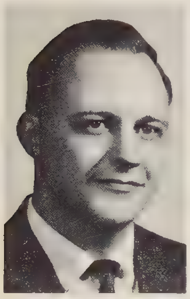
VINCENT D. KAPTUR, JR., co-contributor of "How Human Measurements Are Applied in the GM Comfort Dimensioning System," is chief engineer of the GM Styling Staff's Body Development Studio. He is responsible for the engineer-



ing and design activities associated with the development of body programs for all GM cars. Included in these activities are the design of body structural sections, the development of body surfaces and three-dimensional seating bucks, clay modelings, and the design of passenger compartments.

Mr. Kaptur, who attended Michigan College of Mining and Technology, joined the Styling Staff in 1953 as a junior layout man. Three years later he was promoted to assistant chief engineer of the Body Development Studio. He assumed his present position in 1960.

His technical affiliations include membership in the Engineering Society of Detroit.



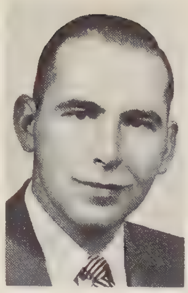
WALTER H. LANGE, co-contributor of "Sensitive Nuclear Techniques Aid Study of Gyroscope Microsyns," is a research physicist with the Physics Department of the GM Research Laboratories.

Mr. Lange joined the Research Laboratories in 1953 as a project mechanic with the Physics Department. In 1956 he was transferred to the Isotope Laboratory. He assumed his present position in 1958 shortly after completing night school study for a B.S. degree from Wayne State University.

He is presently concerned with the application of radioisotope techniques to the solution of various problems received from some GM Divisions, the application of radiotracer techniques to gyro bearing problems and to a study of ball bearing wear and fatigue, and the application of autoradiography to studies of mass transfer and segregation.

Mr. Lange is a charter member of the Michigan Nucleonics Society and is also a member of the American Society of X-Ray Technicians and Alpha Epsilon Delta. He is on the teaching staff of the radioisotope school conducted by the GM Research Laboratories for GM Divisional personnel.

Mr. Lange has authored the chapters on Autoradiography and Radio-chemistry Laboratory Techniques in the book "Radioisotopes in Industry." He has contributed papers to *Nucleonics* and the *General Motors Engineering Journal*.

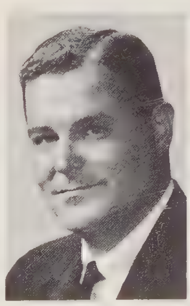


DR. WILLIAM J. MAYER, co-contributor of "Sensitive Nuclear Techniques Aid Study of Gyroscope Microsyns," is a senior research chemist with the Physics Department of the GM Research Laboratories. As a member of this Department's Isotope Laboratory, Dr. Mayer conducts studies to find more useful industrial applications for radioisotopes and also is concerned with research on ball bearing lubrication, production of short-lived isotopes, and metal thickness gaging problems.

Dr. Mayer received the B.S. degree from Wayne State University in 1944 and the Ph.D. degree from the same university in 1950. He is a member of the American Chemical Society and a charter member of the Michigan Nucleonics Society. He also holds membership in Sigma Xi and Phi Lambda Upsilon, honor societies.

Dr. Mayer is a frequent contributor to the literature. He has contributed papers to the *Journal of the American Chemical Society*, *Industrial and Engineering Chemistry*, *Nucleonics*, and the *General Motors Engineering Journal*. He also is a contributing author to the books "Radioisotopes in Industry" and "Nuclear Reactor Experiments."

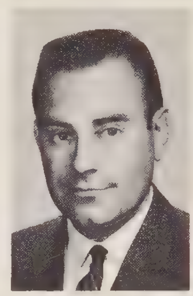
Before joining the GM Research Laboratories in 1956 as a senior research scientist, he was associated with the Argonne National Laboratory's Chemical Engineering Division.



GERALD E. McGLYNN, JR., contributor of "What Does a Patent Cover?" and coordinator of this issue's "Notes About Inventions and Inventors," is a patent attorney in the General Motors Patent Section, Detroit Office. His current work includes the preparation of patent applications and their prosecution before the U.S. and Canadian patent offices. He also negotiates patent licenses and contracts, and investigates proposed production items for possible infringement. His work primarily concerns earth-moving vehicles and equipment, ordnance vehicles, vehicle lamps and lamp manufacturing machinery, and rear view mirrors.

Mr. McGlynn received a bachelor of science in general engineering degree from Iowa State University in 1951. He joined the Patent Section, Washington Office, as a patent engineer in 1953. He attended George Washington University Law School, where he received the LL.B. degree in 1956. While at the university, Mr. McGlynn was patent editor of the *George Washington Law Review*. He was transferred to the Detroit Office as a patent attorney in 1956.

Mr. McGlynn is a registered patent attorney, and is admitted to practice in Michigan and Iowa. He also is a member of the Michigan Patent Law Association, the State Bar of Michigan, and the American Bar Association. He serves on the A.B.A. Committee on patent contracts other than government contracts.



MICHAEL C. MYAL, co-contributor of "How Human Measurements Are Applied in the GM Comfort Dimensioning System," is a project engineer in the Body Development Studio of the GM Styling Staff. He originally joined General Motors in 1949 as an assembler with Fisher Body Division's Pontiac assembly plant. A short time later he entered General Motors Institute as a cooperative engineering student sponsored by Fisher Body and in 1953 was awarded a four-year diploma in automobile body engineering. He then received a *Motor Trend* magazine scholarship to the Art Center School, Los Angeles, where he studied automotive industrial design until his induction into the U.S. Army in 1954. He returned to GM and the Styling Staff in 1957, as a technical stylist in the Body Development Studio, and enrolled in the G.M.I. Fifth Year Program. He received a B.M.E. degree from G.M.I. in 1958 upon completion of a project study assignment entitled "A New Method of Accommodation Dimensioning."

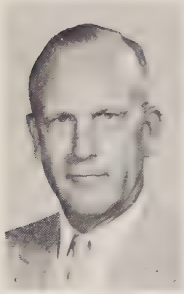
His present work is in the area of passenger compartment design and, in particular, the compilation and presentation of data relating to human accommoda-

tion and space requirements. He is a member of the Society of Automotive Engineers.

CARL F. SCHAEFER, contributor of "A Survey of Some Currently Available Ceramic Materials," is supervisor of ceramic development, Research Laboratory, AC Spark Plug Division. He graduated from the University of Illinois in 1939, receiving the B.S. degree in ceramics. He joined AC Spark Plug that same year as a ceramic engineer and has been engaged in ceramic research and development at this Division ever since.

He has contributed papers to the publications of the American Ceramic Society and is a past chairman of the Whitewares Division of this Society. He also is a member of the Engineering Society of Detroit.

His work in the field of ceramics has resulted in three U.S. patents for a spark plug insulator, a spark plug sealing method, and a method of firing alumina ceramics—the last two with Karl Schwartzwalder. He also was the inventor, with Karl Schwartzwalder and Ralph Mitchell, in a British patent for a low work function alloy.



CARL M. SCHELL, contributor of the problem "Define the Geometry of the Inner and Outer Tooth Contours of a Gear Type Oil Pump," and the solution appearing in this issue, is general supervisor of drafting for Frigidaire Division's Research and Future Products Engineering Department. His responsibilities include supervision of design work on research and developmental programs and also on experimental models for the various products produced by Frigidaire.

Mr. Schell joined Frigidaire in 1929 as a draftsman. A series of promotions, which included senior designer, project engineer, and assistant general supervisor of drafting, led to his present position.

Mr. Schell attended Wittenberg University and the University of Chicago, where he did advanced study in the field of mathematics. He has been on the faculty of Sinclair College since 1936 as a member of the mathematics department and also as a member of the faculty advisory committee.

Three patents have been granted as the result of Mr. Schell's work in the field of refrigeration.

ALLAN F. WEINKAUF, co-contributor of "Sensitive Nuclear Techniques Aid Study of GyroscopeMicrosyns," is chief chemist in the Manufacturing Development Engineering Department at AC Spark Plug Division's Milwaukee plant. His responsibilities include directing electrochemical, plastics, and gyro cleaning process development projects. He also supervises the activities of the Chemistry Laboratory in performing chemical and metallurgical quality control testing and in failure analysis work when chemical or metallurgical analyses are applicable.

Mr. Weinkauf joined AC in 1956 as a process engineer. He was subsequently promoted to senior process engineer and assumed his present position in 1960. Some of his past projects have included work on metal finishing and plastic processing and also development work on such manufacturing processes as plating, painting, anodizing, adhesive application, and epoxy resin encapsulation of electronic devices.

Mr. Weinkauf was granted a B.S. in chemistry degree in 1951 from Beloit College. In 1958 he completed a course conducted by the GM Research Isotope Laboratory in the application and handling of radioisotopes. He is a member of the American Electroplaters' Society and the American Chemical Society.

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General Motors Engineering Journal

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1 January-February-March 1961
2 April-May-June 1961
3 July-August-September 1961
4 October-November-December 1961

Example: 2-38 means page 38 of the April-May-June 1961 issue.

Abbreviations

(CP) Classroom problem
(Ed) Editorial—always appears on unnumbered inside front cover
(P) Portrait

A

B

BACK ISSUES: Readers may obtain back issues of the General Motors Engineering Journal as available upon request to the Educational Relations Section.

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1	January-February-March 1961	3	July-August-September 1961
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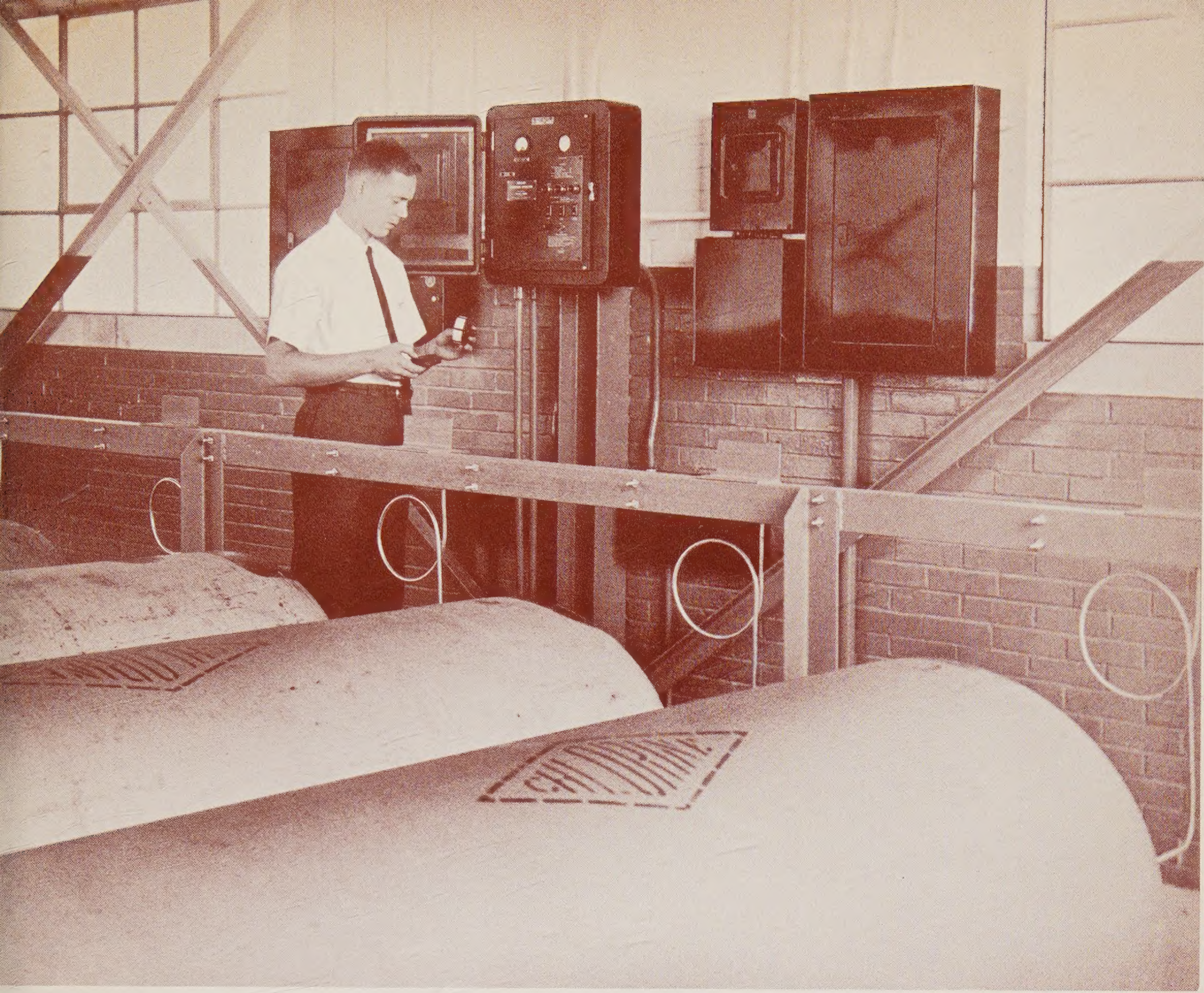

ENGINEERING ASSIGNMENT IN GM

The processes of electroplating, in general, cause waste waters to be formed which cannot be discharged directly into streams without violating state laws covering water pollution. Waste treatment systems, therefore, are installed by plants which produce electroplating wastes.

Richard H. Huibregtse, production engineer at Packard Electric Division, Warren, Ohio, participated in the development and installation of such a treatment system in a new manufacturing building recently completed by this Division. Currently he is responsible for all processes involving electroplating, waste treatment, painting and varnishing, and allied chemical processes.

The new building houses the Division's electroplating processes. The waste treatment system, instead of destroying contaminants in the plating rinse waters, begins by rinsing the plated parts in two separate treatment solutions. One solution contains chlorine and sodium hydroxide for the complete destruction of cyanide wastes. The other solution contains sodium hydrosulfite, soda ash, and hydrated lime for the reduction of hexavalent chromium which is precipitated as chromium hydroxide.

These two independent solutions are circulated from large settling tanks in the treatment area to rinse tanks throughout the Plating Department and back to the settling tanks. In the treatment area, chemicals are continuously added to the solutions and the sludge formed is settled out and discharged to a drying bed.

The photograph shows Mr. Huibregtse checking a chlorine gas detector in the building that houses the chlorine supply. This building is adjacent to the manufacturing building, but is 900 ft. from the plating area. Special procedures are used to assure the safe transporting of chlorine through the building.

Mr. Huibregtse was graduated from the University of Wisconsin in June, 1957, with a B.S. degree in chemical engineering. Shortly afterward, he joined Packard Electric. His early assignments as a junior engineer included modifications to the pickle waste treatment system in the Division's bulk cable plant. This plant contains a copper rod rolling mill and an automatic coil pickling setup. His present position includes supervision of two junior engineers and one technician.

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